An Alternative Approach to Inflation in String Theory

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Autumn workshop on String/M-theory

collaborated with J. X. Lu

Reference List:

Klebanov and Strassler, hep-th/0007191

Giddings, Kachru & Polchinski, hep-th/0105097

Dewolfe & Giddings, hep-th/0208123

Kachru et. al (KKLT), hep-th/0301240

Quevedo, (better review paper), hep-th/0210292

Kachru, et. al, (KKLMMT), hep-th/0308055

Wang & Xiao, hep-th/0410175

Lu & Wang, in prepatre

Out line :

I. Introduction

— Some ideas in string/brane inflation

— D3 - $\overline{D3}$ inflation

— Difficultes

— Our new idea.

II. Dynamics of $\overline{D3}$ -branes in Compactified KS geometry

— world volume action

— Inflaton, effective potential

III. Incorporate inflation

— Various constraint from inflation: slow-roll, Number of e-folding, density perturbation, ...

— Grace exit

— Modulas stabilization

V. Summary & Discussions

I. Introduction

A. Inflation in String/brane models.

— old ideas:

$$10\text{-}d \xrightarrow{\text{compactification}} 4\text{-}d \longrightarrow V_{eff}(\phi_i)$$

ϕ_i: Various moduli from string compactification

$\longrightarrow$ inflaton?

Difficulties: ① It is hard to obtain a flat potential

② In general end with a SUSYic Minkowski or AdS vacuum

— Brane inflation: * Adding probe brane ~~moving~~ in background $R^{1,3} \times \mathcal{M}_6$, with fixing of all of background moduli, and $\mathcal{M}_6$ compactified.

* The positions of brane behave as inflaton.

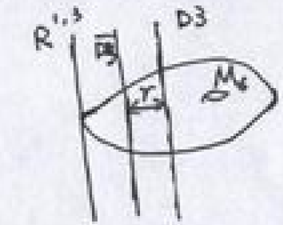
— Braneworld inflation: The Transverse space need not to be compactified. Hard to obtain this type of models from string theory.

B. $D3 - \overline{D3}$ Inflation.

— Basic idea: There is attractive force between D3 & $\overline{D3}$.

$\Rightarrow$ The distance between them decrease

$\Rightarrow$ Now modulus acts as inflation.



— Flat background, with toroidal compactification

$$V(r) = 2T_3\left(1 - \frac{1}{2\pi^4}\frac{T_3 k_{10}^2}{r^4}\right) \qquad T_3 = \frac{1}{(2\pi)^3 g_s l_s^4}$$

$$\rightarrow \quad V(\phi) = 2T_3\left(1 - \frac{T_3^3 K_{10}^2}{2\pi^3\phi^4}\right)$$

* slow-roll parameters: $\epsilon = \frac{M_p^2}{2}\left(\frac{V'}{V}\right)^2 \qquad \eta = M_p^2\frac{V''}{V}$

$$M_p^2 = L^6/k_{10}^2 \quad \Rightarrow \quad \eta = -\frac{10}{\pi^3}\left(\frac{L}{r}\right)^6 \sim -0.3\left(\frac{L}{r}\right)^6 \qquad L > r$$

$\rightarrow$ Does not yield slow-roll!

— In warpped, BPS, with 5-form flux background:

$$ds^2 = e^{2A(r)}dx_\mu dx^\mu + e^{-2A(r)}dy_m dy^m \qquad r^2 = y_m y^m$$

$$C_{(4)} \sim e^{4A(r)}$$

$$V_{eff} = V_0 + \underset{\text{locate at } r_1}{V_{D3}} + \underset{\text{locate at } r_0}{V_{\overline{D3}}} + V_{int}.$$

③

V_0 : Background Vacuum energy after Compactification.

V_{D3} : $\left.\begin{array}{l}\text{Eenergy from tension} \\ \text{Eenergy from } F_{(5)}\end{array}\right\} \rightarrow$ Cancelled by no-force condition

$V_{\overline{D3}}$: $\left.\begin{array}{l}\text{Eenergy from tension} \\ \text{Eenergy from } F_{(5)}\end{array}\right\} \longrightarrow 2T_3 \, e^{4A(r_0)}$

V_{int} : Interaction between D3 & $\overline{D3}$, Composed as follows:

① Adding D3 into background, change background to:

$$e^{-4A(r)} \longrightarrow e^{-4A(r)} + \frac{1}{N} e^{-\Delta A(r, r_1)} \qquad \text{w/: } r_1 - \text{position of D3}$$

② The change of $\overline{D3}$ potential in new background:

$$\delta e^{4A(r_0)} = -\frac{1}{N} 2T_3 \, e^{8A(r_0) - \Delta A(r_0, r_1)} \qquad \text{w/: } r_0 - \text{position of } \overline{D3}$$

$$\Rightarrow \quad V_{eff} = V_0 + 2T_3 \, e^{4A(r_0)}\left(1 - \frac{1}{N} e^{4A(r_0) - \Delta A(r_0, r_1)}\right)$$

Assuming : $V_0 = 0$, $r_0 = \text{Const.}$ $r_1 \rightarrow$ dynamical Variable

$$\Rightarrow \quad \eta = \frac{L^6}{N k_{10}^2 T_3}\left(\Delta A'' - (\Delta A')^2\right) e^{4A(r_0) - \Delta A(r_0, r_1)}$$

* η may be small for N large, $e^{4A - \Delta A}$ small

Example 1: $AdS_5 \times X_5$: $e^{-4A} = \frac{R^4}{r^4}$, $e^{-4A(r,r_1)} = \frac{R^4}{r_1^4}$

$$\eta = \frac{L^6}{N \kappa_{10}^2 T_3} \frac{20 r_0^4}{r_1^6} \simeq \frac{2 L^6 r_0^4}{\pi^4 l_s^4 r_1^6} \ll 1 \quad \text{for} \quad r_1 \gg r_0$$

Example 2: Embedding Klebanov – Strassler Geometry in

F – theory compactification:

After moduli stabilization: $e^{4A_0} \sim e^{-\frac{8\pi k}{3 g_s M}}$,

$$M = \frac{1}{4\pi^2} \int_A F_{(3)} \qquad -k = \frac{1}{4\pi^2} \int_B H_{(3)}$$

can achieve a small η!

C). Incorporate with modulus ~~stat~~ stabilization

— string compactification:

$$ds^2 = e^{-6u(x)} g_{\mu\nu} dx^\mu dx^\nu + e^{2u(x)} (\tilde{g}_{mn}(y) + T^I(x)\, \delta g_{Imn}(y)) dy^m dy^n$$

$\mathrm{Im}\rho = e^{4u} \longrightarrow$ volume modulus $\quad (\rho = \chi + i e^{4u})$

$T^I \longrightarrow$ remaining Kähler & Complex structure moduli

$$V_4 \approx e^{-12u} V_{eff} \sim V_{eff} / (\mathrm{Im}\rho)^3 \sim V_{eff} / L^{12}$$

- Assume ρ-modulus is stabilised by $\mathcal{N}=1$, SUGRA potential:

$$V = e^{K}\left(g^{a\bar{b}} D_a W D_{\bar{b}} \bar{W} - 3|W|^2\right)$$

w/: no-scale type kähler potential, $K = -3\ln(-i(\rho-\bar{\rho}))$

& Non-perturbative superpotential, $W = W(\rho)$

- Insertion of $D3/\overline{D3}$ usually change kähler structure:

$$K = -3\ln(2r), \quad 2r = -i(\rho-\bar{\rho}) + T(\phi,\bar{\phi})$$

w/: $\phi, \bar{\phi}$ - position of $D3/\overline{D3}$, inflaton,

as well as $\mathcal{N}=1$ potential:

$$V = e^{K}\left(g^{a\bar{b}} D_a W \overline{D_b W} - 3|W|^2\right) + \frac{D}{r^2} \rightarrow \text{from } \overline{D3}$$

$$\Rightarrow V = \frac{1}{6r}\left\{|W'|^2\left(1 + \frac{1}{2r}\frac{T_{,\phi} T_{,\bar{\phi}}}{T_{,\phi\bar{\phi}}}\right) - \frac{3}{2r}(WW' + c.c)\right\} + \frac{D}{r^2}$$

w/: $W' = \partial_\rho W$

Usually $D3/\overline{D3}$ are put along radial direction of transverse space:

$$T(\phi,\bar{\phi}) = \sum_n c_n (\phi\bar{\phi})^n$$

$c_1 = T_3 M_p^2$ determined by kinetic term of ϕ:

$$M_p^2 K_{,\phi\bar{\phi}} \partial_\mu \phi \partial^\mu \bar{\phi} \longrightarrow \frac{3T_3}{2\,\mathrm{Im}\,\rho_c} \partial_\mu \phi \partial^\mu \bar{\phi}$$

$\Rightarrow$ Nomalized variable (inflaton): $\varphi = \sqrt{\frac{3T_3}{2\,\mathrm{Im}\rho_c}}\,\phi$

w/: $\rho_c = \text{Const.}$ — stabilized modulus

$$\Rightarrow \quad V = \left(\frac{|W(\rho_c)|^2}{2\,\mathrm{Im}\rho_c} - \frac{1}{4(2\,\mathrm{Im}\rho_c)^2}\left(W(\rho_c)\,W'(\rho_c) + c.c\right) + \frac{D}{(\mathrm{Im}\rho_c)^2} \right)\left(1 + \frac{2}{3M_p^2}\varphi\bar{\varphi}\right)$$

$$\Rightarrow \quad \eta = \frac{2}{3}$$

Conclusion: $D3 - \overline{D3}$ inflation is not consistent with (volume) modulus stabilization!

D): Our new idea:

$D3/\overline{D3}$ - branes in background with 3-form flux:

$\longrightarrow$ Expand into D5 with topology $R^3 \times S^2$

— Radius of S^2 as inflaton!

Background with flux?

Various constraints from inflation?

Compactification & modulus stabilization?

II. Dynamics of $\overline{D3}$ - branes in Compactified KS geometry

— Motivations

* Why Klebanov - strassler geometry ?

- Δ present R-R 3-form flux
- Δ Consistent with F- theory Compactification

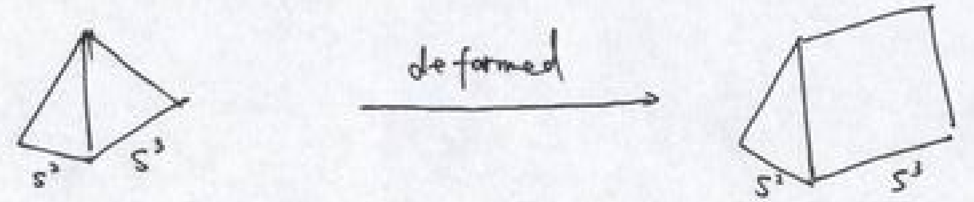
* Why $\overline{D3}$ -branes ?

Extra Energy from tension of $\overline{D3}$ & flux

$\Rightarrow$ AdS phase $\xrightarrow{\text{uplift}}$ dS phase

— The Klebanov - strassler geometry

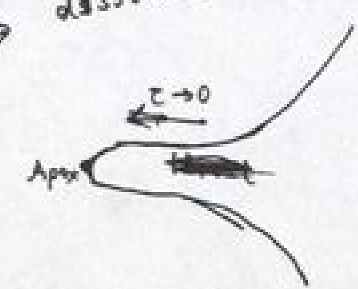
* Deformed conifold :



$x^2+y^2+z^2+w^2=0$ $\qquad\qquad$ $x^2+y^2+z^2+w^2=\varepsilon^2$

* KS geometry : IIB SUGRA solution

$\left.\begin{array}{l} + N\ D3 \\ + M\ D5 \end{array}\right\} \rightarrow$ Apex of deformed conifold $\rightarrow$ dissolve into Fluxes

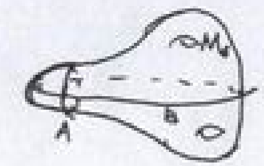


$$ds_{10}^2 = h^{-1/2}(\tau)\, \eta_{\alpha\beta}\, dx^\alpha dx^\beta + h^{1/2}(\tau)\, ds_6^2$$

$F_{(5)}$, $H_{(3)} \neq 0$, $\qquad \phi = \text{Const.}$

— Embedding KS geometry into F-theory Compactification

* Cut KS geometry and smoothly glue with a Compactified manifold M_6



* Tadpole cancellation condition:

$$\frac{\chi(X)}{24} = N_{D3} - N_{\overline{D3}} + \frac{1}{2\kappa_{10}^2 T_3}\int_{M_6} H_{(3)} \wedge F_{(3)}$$

* Dirac Quantization

$$\frac{1}{4\pi^2}\int_A F_{(3)} = M \qquad \frac{1}{4\pi^2}\int_B H_{(3)} = -K$$

— Adding $\overline{D3}$-brane

* Assuming KS geometry has been embedded into F-theory Compactification, without extra insertion of $D3/\overline{D3}$ branes,

• Tadpole condition: $\frac{\chi(X)}{24} = MK$

~~* Now introducing p $\overline{D3}$~~

• We end with an AdS vacuum.

* Now introducing p $\overline{D3}$-branes into background while the topology of CY. 4-fold, X, is not changed. The tadpole condition can be satisfied by turning on more flux:

$$\frac{\chi(X)}{24} = -N_{\overline{D3}} + (M+s)K = MK$$

$$\Rightarrow \quad p = N_{\overline{D3}} = sK, \qquad s \in \mathbb{Z}$$

* The background D3 charge $N = MK$. $\Rightarrow$

The backreaction of $\overline{D3}$ can be ignored when $s \ll M$

* The energy from T_3 & extra flux : $AdS \rightarrow dS$

— World-volume action:

* $S = S_{BI} + S_{CS}$

$$S_{BI} = -T_p \int d^{p+1}\xi \cdot \mathrm{STr}\left\{ e^{-\phi} \left(-\det\left(P[E_{ab} + E_{ai}(Q^{-1}-\delta)^{ij} E_{jb}] + 2\pi l_s^2 F_{ab} \right) \right)^{\frac{1}{2}} \sqrt{\det(Q^i{}_j)} \right\}$$

$$S_{CS} = \mu_p \int \mathrm{STr}\left(P\left[e^{2\pi i l_s^2 i_\Phi i_\Phi} \left(\sum_n C^{(n)} e^{B} \right) \right] e^{2\pi l_s^2 F} \right)$$

$$E_{\mu\nu} = B_{\mu\nu} + G_{\mu\nu}, \qquad T_p = \frac{\mu_p}{g_s} = \frac{1}{g_s (2\pi)^p l_s^{(p+1)}}$$

$$Q^i{}_j = \delta^i{}_j + 2\pi i l_s^2 [\Phi^i, \Phi^j] E_{kj}$$

$$i_\Phi i_\Phi C^{(n)} = \frac{1}{(n-2)!} \Phi^{i_1} \Phi^{i_2} C^{(n)}_{i_1 i_2 \cdots i_n} dx^{i_3} \wedge \cdots \wedge dx^{i_n}$$

* We choose the S^3 of deformed conifold as our solution ansatz. It is embedded into a local flat 3-d space near apex:

$$d\tau^2 + \tau^2 d\Omega_3^2 = dy_1^2 + dy_2^2 + dy_3^2$$

$$\ast\ F_{(3)} \longrightarrow \frac{\sqrt{3}\, \varepsilon^{4/3}}{a_0 g_s M l_s^2} dx_0 \wedge dx_1 \wedge dx_2 \wedge dx_3 \wedge dy_1 \wedge dy_2 \wedge dy_3$$

$$H_{(3)} \longrightarrow \sqrt{3}\, g_s M l_s^2\, dy_1 \wedge dy_2 \wedge dy_3 \iff B_{(2)} = \frac{g_s M l_s^2}{2\sqrt{3}} \epsilon^{ijk} y_i\, dy_j \wedge dy_k$$

* Static gauge: $\xi_a = x_a, \qquad y_i = 2\pi l_s \Phi_i \qquad i = 1, 2, 3$

* Effective potential

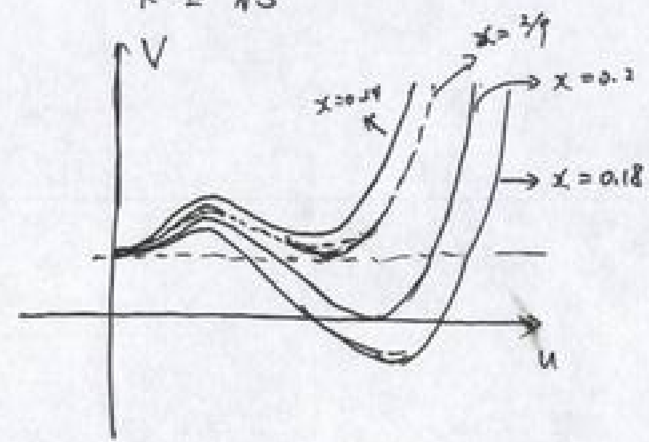
Ansatz for solution of EOM: $\Phi_i = \frac{m^2}{f} u J_i$, $[J_i, J_j] = i \epsilon_{ijk} J^k$

$$\Rightarrow \quad V(u) = V_0 + \frac{p(p^2-1)m^6}{4f^2}\left(\frac{1}{2}u^2 - \frac{1}{3}u^3 + \frac{x}{4}u^4\right)$$

w/: $V_0 = \dfrac{p T_3 \varepsilon^{4/3}}{a_0 g_s^2 M^2 l_s^4}$, $\quad m^2 = \dfrac{2 a_1 \varepsilon^{4/3}}{a_0^2 g_s^2 M^2 l_s^4}$, $\quad f = \dfrac{\sqrt{6\pi}\, \varepsilon^{2/3}}{2 a_0 \sqrt{g_s}\, M l_s^2}$

$$x = \frac{2\pi g_s (1-\lambda) m^2}{f^2} = \frac{8a_1}{3}(1-\lambda), \qquad \lambda = \frac{K^2(p^2-1)}{g_s^2 M^2}$$

$a_0 \simeq 0.718$, $\quad a_1 = 3^{-1/3}$, $\quad K^2 \simeq \sqrt{3}$



* Static solution:

$$u = u_0^{(\pm)} = \frac{1}{2x}\left(1 \pm \sqrt{1-4x}\right)$$

$$V_{max} = V_0 - \frac{p(p^2-1)m^6}{96x^3 f^2}\left[1 - 6x + 6x^2 - (1-4x)^{3/2}\right] \geq V_0 \quad \text{for} \quad x \in [0, 1/4]$$

$$V_{min} = \text{- - - - -} \quad + \cdots \cdots \leq V_0 \quad \text{for} \quad x \in [0, 2/9]$$

- Vacuum at $u = 0$ $(V = V_0)$ $\longrightarrow$ $\overline{D3}$ configuration.
- Vacuum at $u = u_0^{(+)}$ $(V = V_{min})$ $\longrightarrow$ DS configuration $\vee$ $R^3 \times S^3$

III. Incorporate with Inflation

* shift potential by defining: $u = v + u_0^{(-)}$

$$V = V_{\ell max} + \frac{p(p^2-1)m^6}{4f^2}\left\{-\frac{1}{4x}\left(\sqrt{1-4x}-1+4x\right)v^2 + \frac{1}{6}\left(1-3\sqrt{1-4x}\right)v^3 + \frac{x}{4}v^4\right\}$$

* Inflation : $\varphi_i = \frac{m^2}{f^0} v J_i$

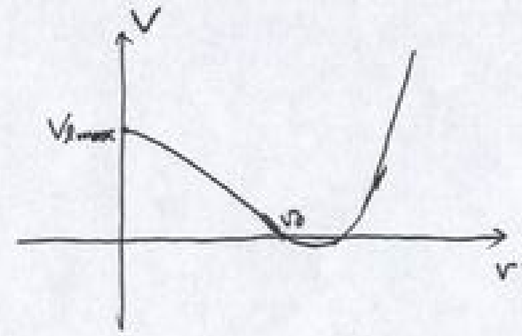
Because we find a homogenous solution, we can use one field replace its effect:

$$\phi = \frac{2m^2}{f} v\sqrt{p(p^2-1)}$$

* Grace exit of inflation:
    - The ~~total~~ energy of system is lowered with decrease of x, and can be even negative!
    - The negative energy is unphysical! There is critical point $v = v_0 \Rightarrow V(v_0) = 0$.
    - The spherical D5-brane at $v = v_0$ annihilates one unit R-R 3-form flux, and dissolve into $(K-p)$ D3-branes:

$$\frac{x}{24} = MK - p = (M-1)K + (K-p)$$

∘ Because critical point is presented only for $x \le 0.198730$,
we require $x \le 0.1987$ in order inflation can ~~start~~ end!

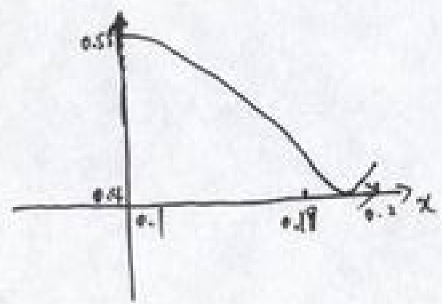


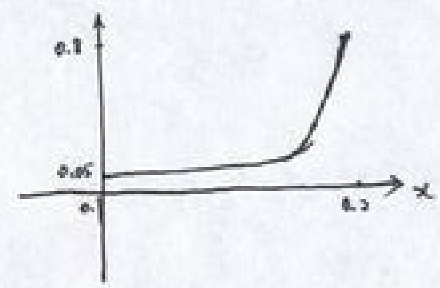
* define

$$S_1(x) = -\frac{2x\left(1-3\sqrt{1-4x}\right)V_0(x)}{3\left(\sqrt{1-4x}-1+4x\right)}$$

$$S_2(x) = \frac{x^2 V_0^2(x)}{\sqrt{1-4x}-1+4x}$$

The curves of S_1 & S_2 are as follows:





In other words, if we expect the inflation occurs between $v=0$ and $v=v_0$, we can ignore v^3 and v^4 terms in potential.

$$\Rightarrow \quad V = \frac{p\, m^6}{4f^2k^2}\left\{ \frac{3a_0^3 k^2}{32\pi^2 a_1^3} - \frac{1}{4x}\left(1-\frac{3x}{8a_1}\right)\left(\sqrt{1-4x}-1+4x\right)v^2 \right\} + O(v^3)$$

* Various constranits from inflation :

$$\epsilon = \frac{\bar{M}_p^2}{2}\left(\frac{V'}{V}\right)^2 \ll 1 \qquad\qquad \bar{M}_p^2 = \frac{2L^6}{(2\pi)^7 \ell_s^8 g_s^2}$$

$$\eta = \bar{M}_p^2 \frac{V''}{V} \ll 1 \qquad\qquad L - \text{scale of compact space}$$

$$N_e = -\frac{1}{\bar{M}_p^2}\int_{\phi_i}^{\phi_f} \frac{V}{V'}\, d\phi \sim 60$$

$$\delta_H \simeq \frac{1}{\bar{M}_p^3}\frac{V^{3/2}}{V'} \sim 10^{-5}$$

$\because$ ✓ $V(v)$ decrease with increase of v

✓ $|V'|$ increase - - — — — .

✓ V'' is nearly constant

$\Rightarrow$ • The maximum of δ_H is at $v = v_i$

• The maximum of ϵ is at $v = v_f$

$\Rightarrow$ • The condition for δ_H tells us where the inflation start

• The condition for ϵ tells - - - - - - — - end

• The condition for η & N_e gives Constranits on background !

* $\epsilon = \frac{\bar{M}_P^2}{2}\left(\frac{V'}{V}\right)^2 \ll 1$

The inflation end at $\epsilon \sim 1$, i.e,

$$\frac{\bar{M}_P^2}{2} \cdot \frac{f^2}{4m^4 p(p^2-1)} \left(\frac{\mu(x)\, v_f}{A - \frac{1}{2}\mu(x)\, v_f^2}\right)^2 < 1$$

w/: $\mu(x) = \frac{1}{2x}\left(1-\frac{3x}{8a_1}\right)\left(\sqrt{1-4x} - 1 + 4x\right)$

$$A = \frac{3a_0^3 K^2}{32\pi^2 a_1^3} \simeq 0.5$$

$$y^2 = \frac{f^2 \bar{M}_P^2}{8m^4 p(p^2-1)} = \frac{3\pi a_0^2 K^2}{4 a_1^2} \cdot \frac{g_s l_s^4 \bar{M}_P^2}{p\,\epsilon^{4/3}} \left(1-\frac{3x}{8a_1}\right)^{-1}$$

$$\simeq \frac{5\, g_s l_s^4 \bar{M}_P^2}{p\,\epsilon^{4/3}} \left(1-\frac{3x}{8a_1}\right)^{-1}$$

$$\Rightarrow \quad v_f < -y + \sqrt{y^2 + \frac{2A}{\mu}}$$

* $\delta_H \sim 10^{-5}$

In order to obtain enough e-folding, the v_i must be sufficiently small, Then

$$\delta_H \simeq \frac{\sqrt{p}\, m^3}{\sqrt{8}\, K f \bar{M}_P^2} \cdot \frac{A^{3/2}}{y \mu v_i} \sim 10^{-5}$$

$$\Rightarrow \quad v_i \sim \frac{10^5 \sqrt{p}\, m^3}{\sqrt{8}\, K f \bar{M}_P^2} \frac{A^{3/2}}{y\mu} \simeq 6\times 10^2 \cdot \frac{\epsilon^2}{g_s p\, l_s^6 \bar{M}_P^3 \mu} \left(1-\frac{3x}{8a_1}\right)^{3/2}$$

$$\simeq \frac{6\times 10^{-20}\, g_s^{1/2}}{p^{3/2}\, y^3 \mu(x)}$$

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* $$N_e = -\frac{1}{\bar{M}_p^2}\int_{\phi_i}^{\phi_f} \frac{V}{V'}\,d\phi$$

$$= \frac{1}{2y^2}\left\{\frac{A}{\mu}\ln\frac{v_f}{v_i} - \frac{1}{4}\mu v_f^2\right\} \sim 60$$

This happens only for $y \ll 1$

$$\Rightarrow \quad N_e \simeq \frac{1}{2y^2}\left\{\frac{A}{2\mu}\ln\left(2A\mu\, p^3/g_s\right) + \frac{3A}{\mu}\ln y - \frac{A}{2} - 6.4\right\} \sim 60$$

To find minimal p^3/g_s, we have:

$$y^2 = \frac{A}{8\cancel{0}\mu}$$

$$\Rightarrow \quad 2A\mu\, p^3/g_s = \frac{(80\mu)^3}{A^3}\, e^{3+26.5\mu}$$

$$\Rightarrow \quad \begin{cases} y^2 \simeq 0.014 \\ p^3/g_s \sim 10^{12} \end{cases} \qquad \text{for} \quad \mu \sim 0.18 - 0.2$$

$$\Rightarrow \quad \frac{g_s}{p}\cdot\frac{l_s^4 \bar{M}_p^2}{\varepsilon^{4/3}} \simeq 2\times 10^{-3}$$

* $$\eta = \bar{M}_p^2 \frac{V''}{V} \leq 4\mu\, y^2/A \simeq 0.045 \ll 1$$

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* More constraints.

- we require radius of fuzzy S^2 must be smaller than L:

$$\frac{\pi l_s p}{\sqrt{g_s M}} < L$$

$$\Rightarrow \quad \frac{p^6}{512\pi^2 l_s^2 g_s^3 M^3} < \bar{M}_P^2 \quad \Rightarrow \quad \frac{p^5 \, l_s^2}{512\pi^2 g_s^2 M^2 \varepsilon^{4/3}} < 2\times 10^{-3}$$

- $$m_{KK} \sim \frac{\varepsilon^{2/3}}{g_s M l_s^2} \sim \frac{10^a}{l_s}$$

- Combination:

$$\frac{p^5}{512\pi^2 g_s^4 M^5} < 2\times 10^{2a-3}$$

$$\Rightarrow \quad g_s < 10^{a+2a}$$

$$\Rightarrow \quad p^3 < 10^{16+2a}$$

- $$\left.\begin{array}{l} g_s < 10^{-1} \\ m_{KK} > 10^3\ \mathrm{GeV} \\ \dfrac{1}{l_s} < 10^{18}\ \mathrm{GeV} \end{array}\right\} \Rightarrow -16 < a < -3$$

$$p^2 \gg 1 \quad \Rightarrow \quad -7 < a < -3$$

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* Modulus stabilization:

Everything like $D3-\overline{D3}$ system, except that we are dealing with a non-Abelain system. Then:

$$T(\phi, \bar{\phi}) = -\frac{p^2-1}{4} T_3 M_p^2 \phi\bar{\phi} + \cdots$$

$\Rightarrow$ kinetic term:

$$M_p^2 K_{,\phi\bar{\phi}} \mathrm{Tr}(\partial_m \phi \partial^m \bar{\phi}) = \frac{3p(p^2-1) T_3}{8\,\mathrm{Im}\,\rho_0} \partial_m \phi \partial^m \bar{\phi}$$

$\Rightarrow$ inflaton: $$\varphi = \sqrt{\frac{3p(p^2-1)T_3}{8\,\mathrm{Im}\,\rho_0}}\ \phi$$

$$\Rightarrow \quad V \propto \left(1 + \frac{2}{3p M_p^2} \varphi\bar{\varphi}\right)$$

$$\Rightarrow \quad \eta = \frac{2}{3p}$$

key point: η is suppressed by $1/p$ comparing with $D3-\overline{D3}$ inflation!

* End of inflation, dS vacuum & c.c.

- Add one unit extra R-R flux and K $\overline{D3}$

  $\longrightarrow$ D5 with $R^3 \times S^2$

  $\longrightarrow$ D5 annihilates with one unit R-R flux

  $\longrightarrow$ End with AdS vacuum.

- Add two unit extra R-R fluxes and 2K $\overline{D3}$

  $\longrightarrow$ D5

  $\longrightarrow$ D5 annihilates one unit R-R flux

  $\longrightarrow$ Remain one unit extra R-R flux and K $\overline{D3}$

The disappear of D5 requires:

$$\frac{(2K)^2}{g_s^2 M^2} = \frac{1}{K^2}\left(1 - \frac{3x_1}{8a_1}\right), \qquad x_1 < 0.2$$

If residual K $\overline{D3}$ form a spherical D5, we require

$$\frac{K^2}{g_s^2 M^2} = \frac{1}{K^2}\left(1 - \frac{3x_2}{8a_1}\right), \qquad x_2 < 2/9$$

$\Rightarrow$ $4x_2 - x_1 = 8a_1 \fallingdotseq 1.85$, it is impossible! $\Rightarrow$ K $\overline{D3}$ is stable

$\Rightarrow$ we can end with a dS vacuum with small c.c.

Summary:

* we propose a new approach on brane inflation.
  - $\bar{D3}$ -branes in KS geometry
  - Myers' effect.
  - Radius of fuzzy S^2 as inflaton
* It satisfies all constraints from inflation.
  - ~~[illegible]~~ slow-roll, Grace exit.
  - Number of e-foldings
  - scalar perturbation,
  - need large number of flux unless g_s very small.
* Consistent with (volume) modulus stabilization
* Theoretical constraints:
  - $g_s \ll 1$
  - $p^3/g_s \sim 10^{12}$
  - $p \sim g_s M$