Toward Holographic Glueball Inflation

Lilia Anguelova

INRNE, Bulgarian Academy of Sciences

arXiv:1412.8422 [hep-th]; arXiv:1512.08556 [hep-th]

(with P. Suranyi, L.C.R. Wijewardhana)

Motivation

Cosmological Inflation:

Needed to solve several problems, chief among them being homogeneity and isotropy of the Universe on large scales

Inflationary expansion: driven by the potential energy of a scalar field (inflaton)

Standard description:

A weakly coupled Lagrangian for the inflaton within QFT framework

BUT:

η problem:

Recall the slow roll conditions:

$$\varepsilon = \frac{V'(\varphi)}{V(\varphi)} \ll 1 \quad , \quad \eta = \frac{V''(\varphi)}{V(\varphi)} \ll 1$$

(consistency with observations $\Rightarrow$ slow roll inflation)

However: Quantum corrections drive inflaton mass ($m_\varphi^2 = V''$) to cutoff of effective theory (at least Hubble scale $H \approx \sqrt{V}$)

$\rightarrow$ $\Delta\eta \approx \mathcal{O}(1)$ or larger $\Rightarrow$ inflation ends prematurely

Hence need a symmetry... (ex.: axion monodromy inflation...)

Composite Inflation:

A possible different approach:

Inflaton - a composite state in a strongly coupled gauge theory

[F. Bezrukov, P. Channuie, J. Joergensen, F. Sannino, arXiv:1112.4054; inflaton - glueball]

$\rightarrow$ inflaton mass dynamically fixed $\Rightarrow$ no η problem!

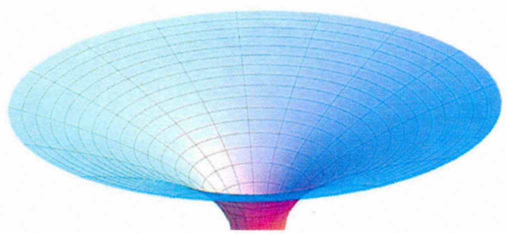
Recently was argued that tensor-to-scalar ratio r can be large in such models [P. Channuie, K. Karwan, arXiv:1404.5879]

Our aim: Use Gauge/Gravity Duality (GGD) to study this class of inflationary models

Gauge/Gravity Duality

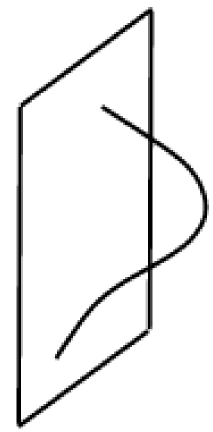
(AdS/CFT correspondence)

Two different perspectives on D-branes in string theory:



gravity background
[SUGRA solution]

$\longleftrightarrow$



open strings BCs
[gauge theory]

A stack of large number of D-branes:

Two sides of duality encode same degrees of freedom

[The two sides have equal partition functions!]

Gravity Backgrounds

Solutions of 10d SUGRA equations of motion

If a lower dimensional consistent truncation exists

$\Rightarrow$ we can, instead, study solutions of the lower dim. effective action for the relevant subset of fields

(Recall: Consistent truncation means that every solution of the lower dimensional action lifts to a solution of the full 10d action)

We will investigate a 5d consistent truncation of type IIB, established in [M. Berg, M. Haack, W. Muck, hep-th/0507285]

(This encompasses MN, KS solutions, but we will look for nonsusy ones.)

Consistent truncation:

IIB SUGRA:

– Bosonic fields: g_{MN}, Φ, C, H_3, F_3, F_5

– Ansatz for the consistent truncation:

$$ds^2_{10d} = e^{2p-q} ds^2_{5d} + e^{q+u}(\omega_1^2 + \omega_2^2) + e^{q-u}\left[(\tilde{\omega}_1 + v\omega_1)^2 + (\tilde{\omega}_2 - v\omega_2)^2\right]$$
$$+ e^{-6p-q}(\tilde{\omega}_3 + \omega_3)^2 \quad , \qquad ds^2_{5d} = g_{IJ}\, dx^I dx^J \quad ,$$

$$\tilde{\omega}_1 = \cos\psi d\tilde{\theta} + \sin\psi \sin\tilde{\theta} d\tilde{\varphi} \quad , \qquad \omega_1 = d\theta \quad ,$$
$$\tilde{\omega}_2 = -\sin\psi d\tilde{\theta} + \cos\psi \sin\tilde{\theta} d\tilde{\varphi} \quad , \qquad \omega_2 = \sin\theta d\varphi \quad ,$$
$$\tilde{\omega}_3 = d\psi + \cos\tilde{\theta} d\tilde{\varphi} \quad , \qquad \omega_3 = \cos\theta d\varphi$$

(Topology of internal 5d: $S^1 \times S^2 \times S^2$)

Ansatz continued:

$$\Phi = \phi(x^I) \quad , \quad C = 0 \quad , \quad H_3 = 0 \quad ,$$

$$F_3 = P\,[-(\tilde{\omega}_1 + b d\theta) \wedge (\tilde{\omega}_2 - b \sin\theta d\varphi) \wedge (\tilde{\omega}_3 + \cos\theta d\varphi)$$
$$+ (\partial_I b)\, dx^I \wedge (-d\theta \wedge \tilde{\omega}_1 + \sin\theta d\varphi \wedge \tilde{\omega}_2)$$
$$+ (1 - b^2)(\sin\theta d\theta \wedge d\varphi \wedge \tilde{\omega}_3)\,,$$

$$F_5 = \mathcal{F}_5 + \star\mathcal{F}_5 \ , \ \mathcal{F}_5 = Q\, vol_{5d} \ , \ P = const \ , \ Q = const$$

$\rightarrow$ 5d fields:

- metric: $g_{IJ}(x^I)$
- 6 scalars: $\phi(x^I)$, $p(x^I)$, $q(x^I)$, $u(x^I)$, $v(x^I)$, $b(x^I)$

[Note: Possible to extend considerations to $H_3 \neq 0$ ...]

5d action:

Let us denote $\{\varphi^i\} = \{\phi, p, q, u, v, b\}$:

$$S = \int d^5x \sqrt{-detg} \left[-\frac{R}{4} + \frac{1}{2} G_{ij}(\varphi) \partial_I \varphi^i \partial^I \varphi^j + V(\varphi) \right],$$

$G_{ij}(\varphi)$ - sigma model metric ,

$V(\varphi)$ - complicated potential

Equations of motion:

$$\begin{aligned} \nabla^2_{5d} \varphi^i + \mathcal{G}^i{}_{jk} \, g^{IJ} (\partial_I \varphi^j)(\partial_J \varphi^k) - V^i &= 0 \, , \\ -R_{IJ} + 2G_{ij} (\partial_I \varphi^i)(\partial_J \varphi^j) + \frac{4}{3} g_{IJ} V &= 0 \, , \end{aligned}$$

$\mathcal{G}^i{}_{jk}$ - Christoffel symbols for G_{ij} , $V^i = G^{ij} \partial_{\varphi^j} V$.

dS and Inflationary Solutions

Want to find a solution with the 5d metric:

$$ds^2_{5d} = e^{2A(r)}\left[-dt^2 + a(t)^2 d\vec{x}^2\right] + dr^2$$

[K. Ghoroku, M. Ishihara, A. Nakamura, hep-th/0609152: Used a 10d solution in IIB with such external 5d metric and $a(t) = e^{\sqrt{\frac{\Lambda}{3}}\,t}$ to study gauge theory in dS space. But the two scalars in that solution: $\phi(r)$, $C(r)$ $\Rightarrow$ not compatible with above consistent truncation.]

Hubble parameter: $\quad H(t) \equiv \dfrac{\dot{a}(t)}{a(t)} \quad \left(\Rightarrow \; \dot{H} = \dfrac{\ddot{a}}{a} - H^2\right)$

Note:
- dS space: $\quad H = const$
- Slow roll inflation: $\quad H = H(t)$, but $\dot{H}$ small

[More precisely: $\ddot{a} > 0 \;\Leftrightarrow\; \epsilon \equiv -\frac{\dot{H}}{H^2} < 1$; slow roll: $\epsilon \ll 1$]

Solving the coupled system of EoMs:

- Subtruncation of the consistent truncation:

  Can consistently set $u \equiv 0\,,\ v \equiv 0\,,\ b \equiv 0$

  [EoMs identically solved]

  $\rightarrow$ Study class of solutions with only nontrivial scalars:

  $$\phi(x^I)\ ,\ p(x^I)\ ,\ q(x^I)$$

- Look for quasi-de Sitter solutions (i.e. with $H \approx const$):

In gauge/gravity duality context: these scalar fields - glueballs

Discrete mass spectrum $\rightarrow$ inflaton mass dynamically fixed

$\Rightarrow$ No η problem!

BUT:

Number of EoMs for scalar fields and metric functions is with one more than number of unknown functions

$\rightarrow$ No solution?

Fortunately, we showed: [as long as $A'(r) \neq 0$]

One equation is dependent on the others!

Solutions with $H = const$:

- 3-parameter family with $q = -6\,p$ and $\phi = 0$

  [analytical solution]

- two 4-parameter families with $q = -\frac{3}{2}p$ and $\phi = 3\,p$

  [numerical solutions]

Solutions with time-dependent H:

Look for small time-dependent deviations from exact $H = const$ (i.e. pure dS) solution: [Recall: $-\frac{\dot{H}}{H^2} \ll 1$]

$\rightarrow$ Deform 5d metric ansatz and ansatz for scalar field(s)

$$\text{Metric:} \quad ds_5^2 = e^{2A}\left[-dt^2 + e^{2\tilde{H}} d\vec{x}^2\right] + dr^2$$

- Expand in $\gamma \ll 1$ around the analytical solution:

$$\begin{aligned} \phi &= \gamma\,\phi_{(1)} + \gamma^3\phi_{(3)} + \mathcal{O}(\gamma^5) \\ A &= A_{(0)} + \gamma^2 A_{(2)} + \mathcal{O}(\gamma^4) \\ \tilde{H} &= \tilde{H}_{(0)} + \gamma^2 \tilde{H}_{(2)} + \mathcal{O}(\gamma^4)\,, \end{aligned}$$

where $A_{(0)} = A_0 \quad , \quad \tilde{H}_{(0)} = H_0\, t$

At order γ:

Single equation for $\phi_{(1)}(t,r)$ with solution:

$$\phi_{(1)} = C_\phi + \tilde{C}\, e^{kt}\,(r+C)^\alpha \ , \quad C_\phi\,,\tilde{C} = const \ ,$$

k, α - parameters depending on H_0

At order γ^2:

Coupled system for $A_{(2)}$, $\tilde{H}_{(2)}$ containing also $\phi^2_{(1)}$ terms

A solution: $A_{(2)} = C_a\, e^{-6H_0 t} \ , \quad \tilde{H}_{(2)} = \hat{C}_H + C_h\, e^{-6H_0 t}$

where $C_a\,, C_h\,, \hat{C}_H = const \ ,$

for $\alpha = 0$ and $k = -3H_0$

Leading order solution:

Coord. transformation $t \to \tau$, such that $d\tau = e^{\gamma^2 A_{(2)}(t)} dt$

$$\Rightarrow \qquad ds_5^2 = e^{2A_0(r)} \left[-d\tau^2 + e^{2\tilde{H}(\tau)} d\vec{x}^2 \right] + dr^2 \ ,$$

where $\tilde{H}(\tau) = H_0 \tau + \gamma^2 \left[\hat{C}_H + \left(\frac{7}{6} C_a + C_h \right) e^{-6h\tau} \right] + \mathcal{O}(\gamma^4)$

→ Hubble parameter:

$$H = H_0 - 6H_0 \left(\frac{7}{6} C_a + C_h \right) e^{-6H_0\tau} \gamma^2 + \mathcal{O}(\gamma^4)$$

→ Inflaton field:

$$\phi = \gamma \left(C_\phi + \tilde{C} e^{-3H_0\tau} \right) + \mathcal{O}(\gamma^3)$$

Ultra-slow roll inflation:

Inflationary slow roll parameters:

$$\varepsilon = -\frac{\dot{H}}{H^2} \qquad \text{and} \qquad \eta = -\frac{\ddot{\phi}}{H\dot{\phi}}$$

For our solution:

$$\varepsilon \sim \mathcal{O}(\gamma^2) \ll 1 \qquad , \qquad \eta = 3 + \mathcal{O}(\gamma^2) \approx 3$$

$\rightarrow$ Ultra-slow roll inflation [arXiv:gr-qc/0503017, W. Kinney]

(Inflaton: $\phi = C_1 + C_2\, e^{-kt}$ with $C_1, C_2, k = const$)

Gives $n_s \approx 1$ (i.e. scale-invariant spectrum), but does not last for more than a few e-foldings

Ultra-slow roll inflation:

$\Rightarrow$ Can only be a transient phase, before usual slow roll

However, such a phase could explain low-l anomaly in CMB power spectrum

[$l \lesssim 40$ – power deficit ($\sim$ 10 %) compared to slow roll expectation]

(lower l – larger angular scales)

Toward slow roll:

– time-dependent deformations of numerical solutions ?...

– different deformation ansatz ?...

– going to higher order in γ in our ansatz ?...

Summary

Found so far:

- Three multi-parameter solutions in 5d consistent truncation of IIB supergravity

  [dS_4 space fibered over the fifth dimension]

- Ultra-slow roll glueball inflation model [t-dep. deformation]

Open issues:

- Slow roll Glueball Inflation ?...
- Microscopic realization ?...
- Inflaton mass (mass-spectrum of fluctuations) ?...

Thank you!