Holography for Composite Inflation

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arXiv:1412.8422 [hep-th]; arXiv:1512.08556 [hep-th]; arXiv:1611.00295 [hep-th]

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

Cosmological Inflation:

Standard description:

– expansion driven by the potential energy of a scalar field φ called inflaton

– weakly coupled Lagrangian for the inflaton within QFT framework:

$$S = \int d^4x \sqrt{-\det g} \left[\frac{R}{2} + \frac{1}{2} g^{\mu\nu} \partial_\mu \varphi \, \partial_\nu \varphi - V(\varphi) \right]$$

– preferably: small field models

($\Delta\varphi \ll M_P \quad \Rightarrow \quad$ EFT reliable)

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:

D-branes: open string BCs $\longleftrightarrow$ SUGRA solutions

strong coupling $\longleftrightarrow$ weak coupling

$\Rightarrow$ Can use classical supergravity to learn about strongly coupled gauge theories

Some potential applications:

- high T_c superconductivity
- quark-gluon plasma [viscosity/entropy density]
- dynamical electroweak symmetry breaking
- composite (in particular, glueball) inflation

Gravity Backgrounds

Solutions of 10d SUGRA equations of motion

Consistent truncation: significant simplification

(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.)

$\rightarrow$ 5d fields:

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

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

Note:
- dS space: $H = const$
- Slow roll inflation: $H = H(t)$, 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)

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

- 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 $A_{(0)}$, $\tilde{H}_{(0)} = H_0\, t$ - an. sol.

Leading order solution:

At order γ: Single equation for $\phi_{(1)}$

At order γ^2: Coupled system for $A_{(2)}$, $\tilde{H}_{(2)}$, incl. $\phi_{(1)}^2$ terms

$\rightarrow$ Obtain explicit solutions: $H(t)$ and $\phi(t)$

Recall that inflationary slow roll parameters:

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

For our solution:

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

Ultra-slow roll inflation:

For inflationary parameters $\varepsilon \ll 1$ and $\eta = 3$:

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

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

$\Rightarrow$ 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 inflation: (arXiv:1611.00295 [hep-th])

Consider higher order in γ:

$$\begin{aligned}\phi &= \gamma\,\phi_{(1)} + \gamma^3\phi_{(3)} + \mathcal{O}(\gamma^5)\\ A &= A_{(0)} + \gamma^2 A_{(2)} + \gamma^4 A_{(4)} + \mathcal{O}(\gamma^6)\\ \tilde{H} &= \tilde{H}_{(0)} + \gamma^2 \tilde{H}_{(2)} + \gamma^4 \tilde{H}_{(4)} + \mathcal{O}(\gamma^6)\end{aligned}$$

Take: $\phi_{(1)} = 0 \quad , \quad A_{(2)} = 0 \quad , \quad H_{(2)} = 0$

(Satisfies the EoMs to order γ^2.)

So to leading order in γ: $\phi \sim \mathcal{O}(\gamma^3) \quad \rightarrow \quad \phi^2 \sim \mathcal{O}(\gamma^6)$

$\Rightarrow$ EoMs for $A_{(4)}$, $\tilde{H}_{(4)}$ decouple from $\phi_{(3)}$!

(Ultra-slow roll solution above: $A_{(2)}$, $\tilde{H}_{(2)}$, $\phi_{(1)}^2 \sim \mathcal{O}(\gamma^2)$.)

Toward slow roll inflation:

$\rightarrow$ Solutions for $A_{(4)}$, $\tilde{H}_{(4)}$ are independent of $\phi_{(3)}$ and vice versa

In particular, integration constants in $\phi_{(3)}$ are unrelated to those in $A_{(4)}$, $\tilde{H}_{(4)}$

This relaxes constraint that led to ultra-slow roll at $\mathcal{O}(\gamma^2)$

$\Rightarrow$ Can show that, for suitable choices of the integration constants, one can obtain:

$$\eta \ll 1$$

$\rightarrow$ Slow roll regime !

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]
- Showed that it is possible to obtain slow roll regime

Open issues:

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

Thank you!