Glueballs as Inflatons

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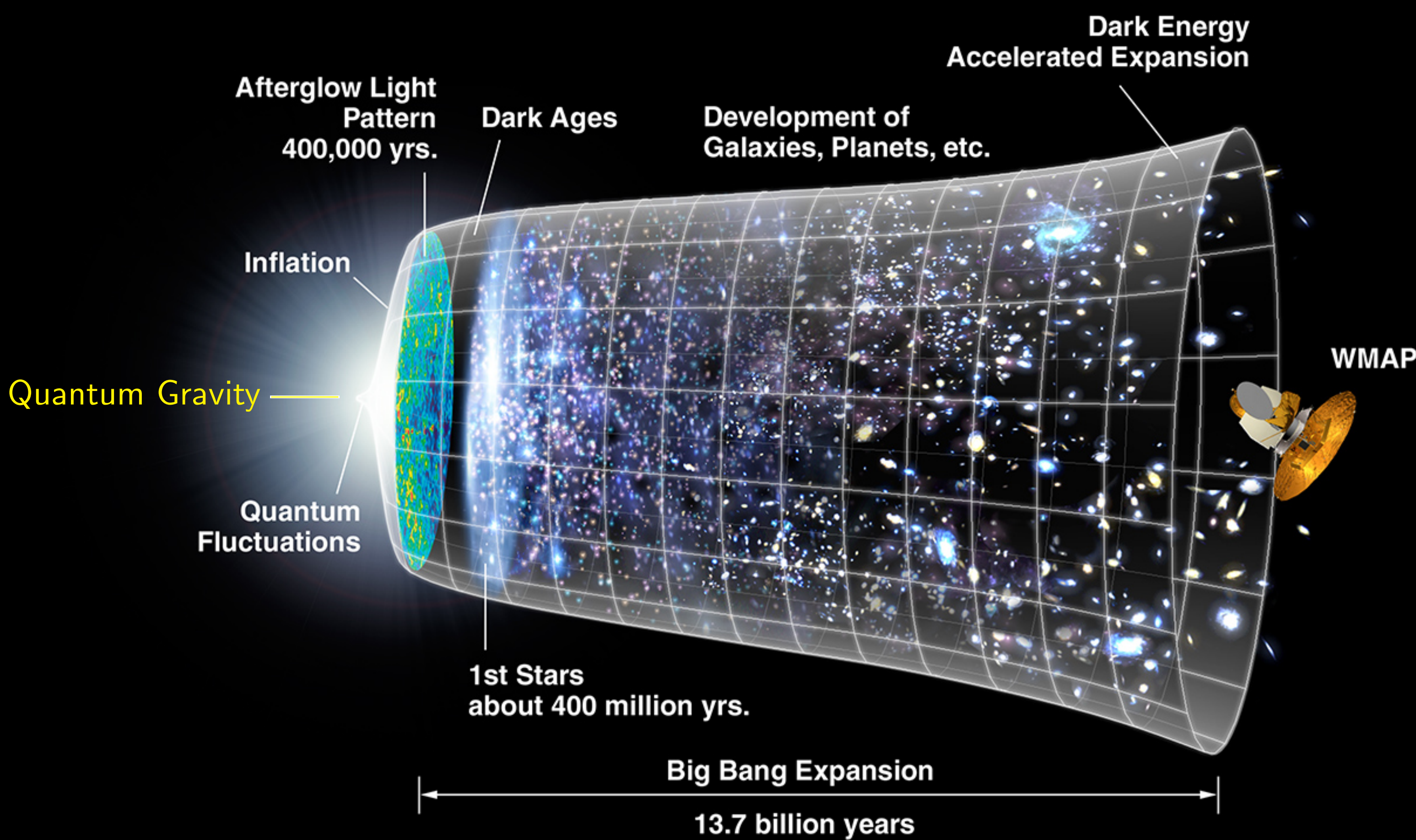
Inflation: Traces of Quantum Gravity ?



(Shortly after) Big Bang: Origin of all structure we see today!

NASA/WMAP Science Team

Cosmological Inflation:

Motivation: reviewed in previous talks

(homogeneity, isotropy of Universe on large scales)

Standard description:

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

– weakly coupled Lagrangian for the inflaton within QFT framework

– 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...)

More recently:

– BICEP2 data may indicate "large" gravitational waves

(i.e. tensor to scalar ratio $r \approx 0.1$)

$\Rightarrow$ inflaton excursion $\Delta\varphi \sim \mathcal{O}(M_P)$ in field space

(due to Lyth bound: $\sqrt{r} < \mathcal{O}(10^{-1})\,\Delta\varphi$, D. Lyth, hep-th/9606387)

– In fact, even without BICEP2:

J. Garcia-Bellido, D. Roest, M. Scalisi, I. Zavala, arXiv:1408.6839 [hep-th]:

$\Delta\varphi$ - super-Planckian for $r > 2 \times 10^{-5}$!

(due to: $\Delta\varphi$ depends on both r and n_s)

If primordial gravitational waves observed (soon):

$\rightarrow$ Need: larger framework (beyond EFT), strong coupling ?

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]

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

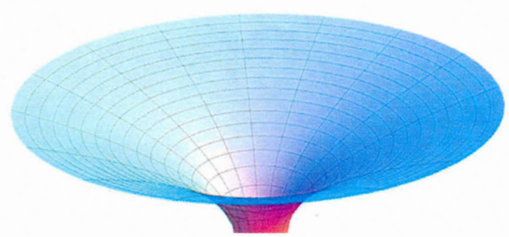
Our aim: Use Gauge/Gravity Duality (GGD) to study this class of inflationary models

(Recall: GGD - powerful nonperturbative method for studying strongly coupled gauge theories)

Gauge/Gravity Duality

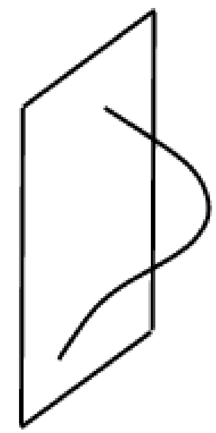
(AdS/CFT correspondence)

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: One could have $H_3 \neq 0$, but things get quite complicated...]

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:

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

$\mathcal{G}^i{}_{jk}$ - 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:

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

[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: $\phi(z)$, $C(z)$ $\Rightarrow$ not compatible with above consistent truncation.]

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

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:

In full generality, system is daunting!...

Any simplification(s)?:

Can consistently set $u \equiv 0\,,\, v \equiv 0\,,\, b \equiv 0$ $(\star)$

[Reason: Each term in their EoMs is proportional to at least one power of u, v or b. So $(\star)$ identically solves those three EoMs.]

- Will look for class of solutions with only nontrivial scalars:

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

- Also, will work in limit $P \gg 1$.

[Note: In MN(-like) solution(s) $P = N_c/4$.]

In $P \gg 1$ limit:

Can show: If $Q = 0$ and $\phi = -2q$, then $\mathrm{EoM}_\phi \longleftrightarrow \mathrm{EoM}_q$

$\rightarrow$ Take $\boxed{Q = 0 \ , \ \phi(x^I) = -2q(x^I)}$

$\Rightarrow$ Two independent scalars left: $\phi(t,z)$, $p(t,z)$.

[plus $A(z)$, $H(t)$]

Remaining system can be solved by $\phi = \phi(z)$, $p = p(t)$.

$\rightarrow$ $p(t)$ - our inflaton.

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

Discrete mass spectrum $\rightarrow$ inflaton mass dynamically fixed

$\Rightarrow$ No η problem!

Summary

Found so far: (to appear)

- Inflationary solution in 5d consistent truncation of IIB

  [pure dS solution: for $p(t) = \text{const}$]

- Inflaton - a glueball $\Rightarrow$ no η problem !

Open issues:

- More general solutions ?...
- Microscopic realization ?...
- Inflaton mass (mass-spectrum of fluctuations) ?...

Thank you!