

dS Space in Gauge/Gravity Duality

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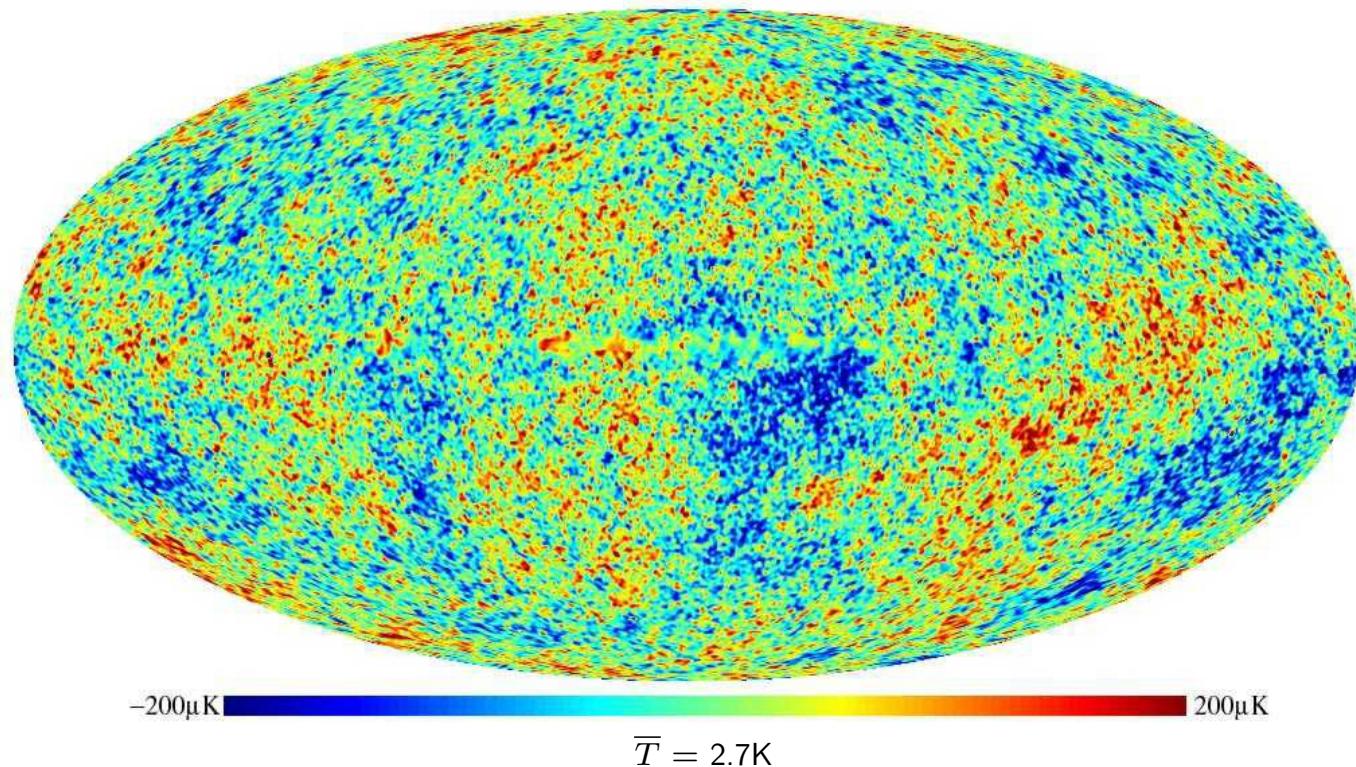
(with P. Suranyi, L.C.R. Wijewardhana)

Motivation

Cosmic Microwave Background (CMB) radiation:

WMAP (2003-2012) and Planck (2013) satellites:

Detailed map of CMB temperature fluctuations on the sky



According to CMB data:

Temperature fluctuations $\frac{\delta T(\theta, \varphi)}{\bar{T}}$, (θ, φ) coord. on S^2 ,
measured with great precision:

- On large scales:

Universe is **homogeneous and isotropic**

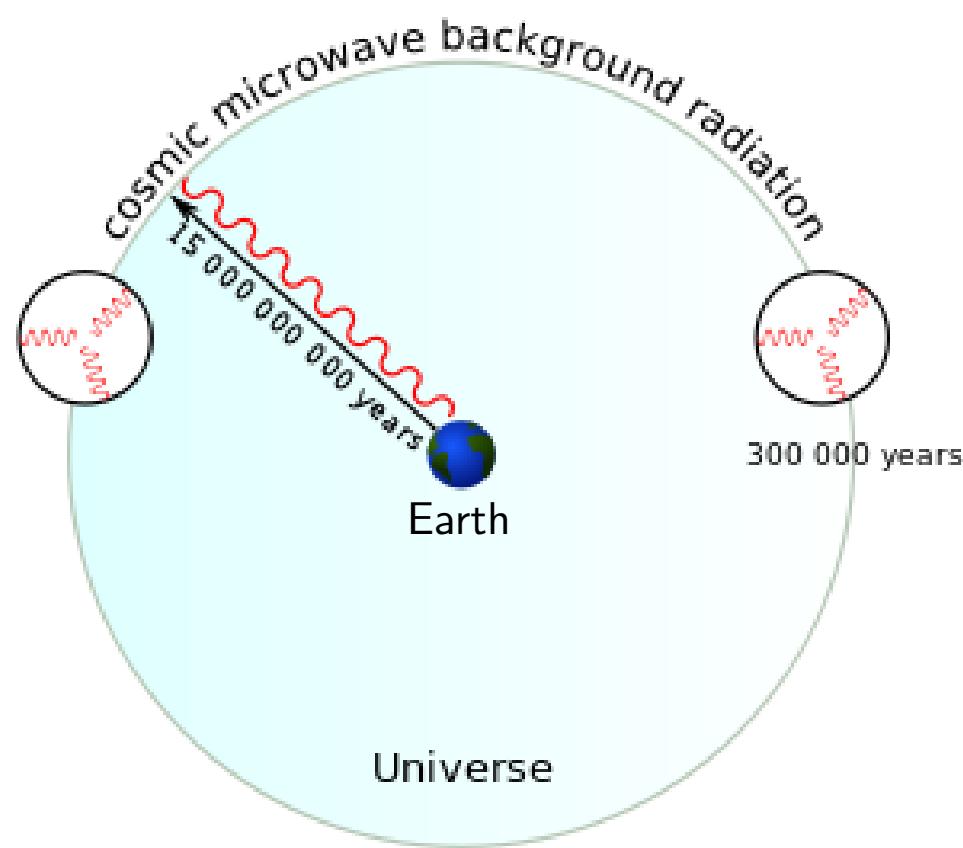
- In Early Universe:

Small perturbations that seed structure formation

[(Clusters of) Galaxies]

Cosmological Inflation:

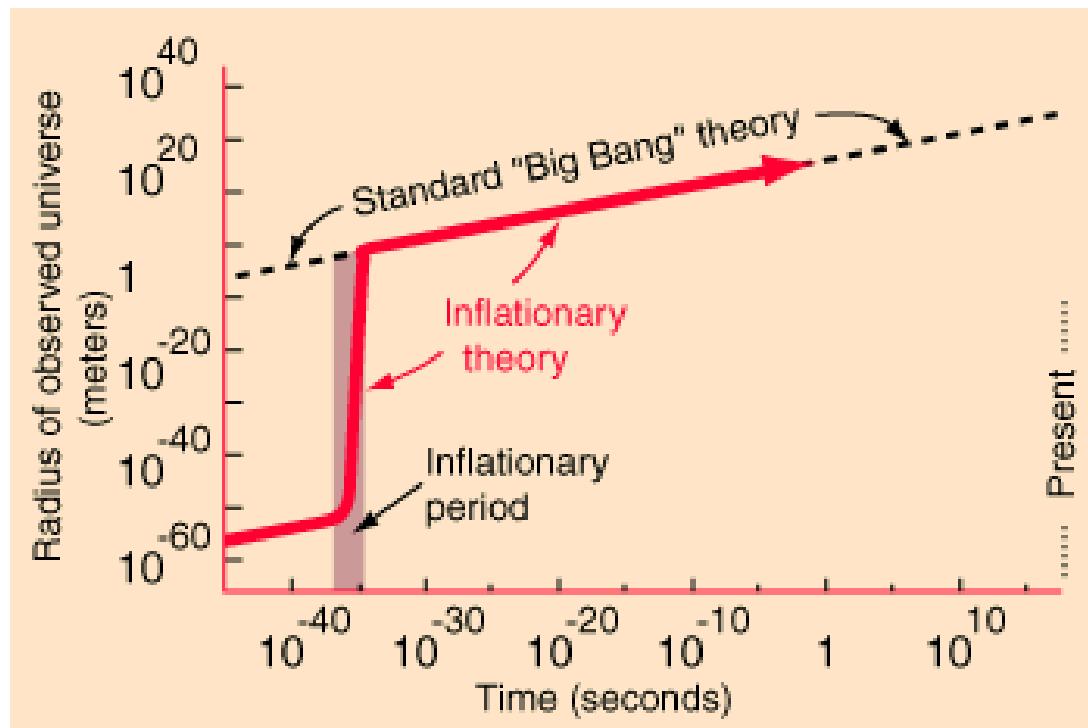
Question: How can CMB be so uniform, if when it formed Universe had many causally disconnected regions ?!?



Cosmological Inflation:

Answer: Period of very fast expansion of space in Early Universe
(faster than speed of light)

⇒ homogeneity and isotropy observed today



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
 $(\Delta\varphi \ll M_P \Rightarrow \text{EFT reliable})$

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]

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

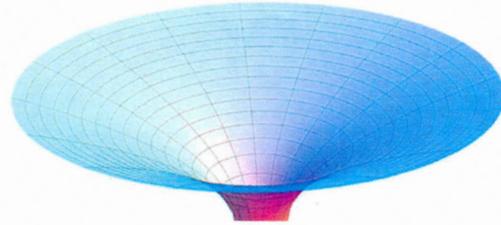
Our aim: Use Gauge/Gravity Duality (GGD) to study this class of inflationary models

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

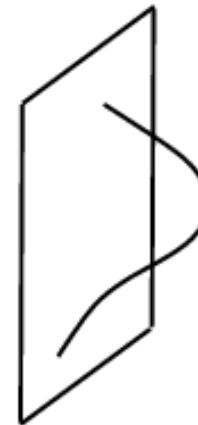
Gauge/Gravity Duality

(AdS/CFT correspondence)

Two different perspectives on D-branes in string theory:



gravity background
[SUGRA solution]



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

⇒ 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: $g_{MN}, \Phi, C, H_3, F_3, F_5$
- Ansatz for the consistent truncation:

$$ds_{10d}^2 = e^{2p-q} ds_{5d}^2 + e^{q+u} (\omega_1^2 + \omega_2^2) + e^{q-u} [(\tilde{\omega}_1 + v\omega_1)^2 + (\tilde{\omega}_2 - v\omega_2)^2]$$

$$+ e^{-6p-q} (\tilde{\omega}_3 + \omega_3)^2 \quad , \quad ds_{5d}^2 = g_{IJ} dx^I dx^J \quad ,$$

$$\tilde{\omega}_1 = \cos \psi d\tilde{\theta} + \sin \psi \sin \tilde{\theta} d\tilde{\varphi} \quad , \quad \omega_1 = d\theta \quad ,$$

$$\tilde{\omega}_2 = -\sin \psi d\tilde{\theta} + \cos \psi \sin \tilde{\theta} d\tilde{\varphi} \quad , \quad \omega_2 = \sin \theta d\varphi \quad ,$$

$$\tilde{\omega}_3 = d\psi + \cos \tilde{\theta} d\tilde{\varphi} \quad , \quad \omega_3 = \cos \theta d\varphi$$

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

Ansatz continued:

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

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

$$F_5 = \mathcal{F}_5 + \star \mathcal{F}_5 \quad , \quad \mathcal{F}_5 = Q \text{vol}_{5d} \quad , \quad P = \text{const} \quad , \quad Q = \text{const}$$

→ 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 $H_3 \neq 0 \dots$]

5d action:

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

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

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

$V(\varphi)$ - complicated potential

Equations of motion:

$$\nabla_{5d}^2 \varphi^i + \mathcal{G}^i{}_{jk} g^{IJ} (\partial_I \varphi^j) (\partial_J \varphi^k) - V^i = 0 ,$$

$$-R_{IJ} + 2G_{ij}(\partial_I \varphi^i)(\partial_J \varphi^j) + \frac{4}{3} g_{IJ} V = 0 ,$$

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

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

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

Note: • dS space: $H = \text{const}$

• 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]

→ 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 $H \approx \text{const}$):

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

Discrete mass spectrum → inflaton mass dynamically fixed

⇒ **No η problem!**

BUT:

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

→ No solution?

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

One equation is dependent on the others!

Solutions with $H = \text{const.}$:

- 3-parameter family with $q = -6p$ and $\phi = 0$
[analytical solution]
- two 4-parameter families with $q = -\frac{3}{2}p$ and $\phi = 3p$
[numerical solutions]

Summary

Found so far:

[arXiv:1412.8422, L.A., P. Suranyi, R. Wijewardhana]

- Three multi-parameter solutions in 5d consistent truncation of IIB supergravity
 - [dS_4 space fibered over the fifth dimension]
 - Recall: Inflaton - a glueball \Rightarrow no η problem !

Open issues:

- Time-dependent deformations [Glueball Inflation] ?...
- Microscopic realization ?...
- Inflaton mass (mass-spectrum of fluctuations) ?...

Thank you!