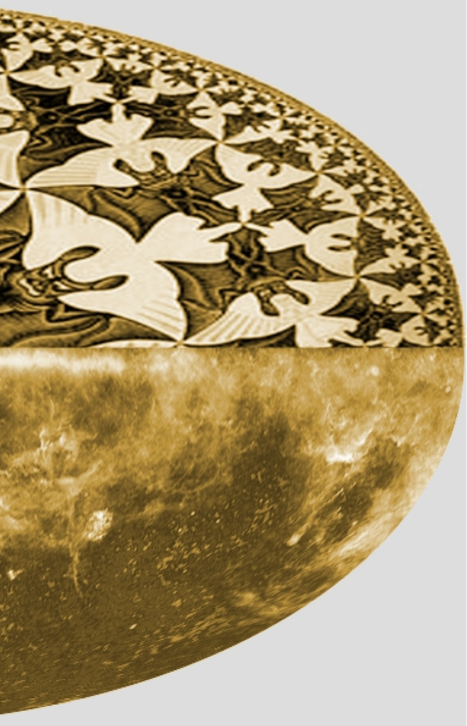

Holography for slow-roll inflation

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Introduction

In this talk we present a precise and quantitative holographic decription of a class of inflationary slow-roll models.

Through calculations in the three-dimensional dual QFT, we can derive

1. The inflationary power spectrum to second order in slow-roll
2. Non-Gaussianities

References

1. The power spectrum of inflationary cosmologies dual to a deformed CFT.

   McFadden [1308.0331]

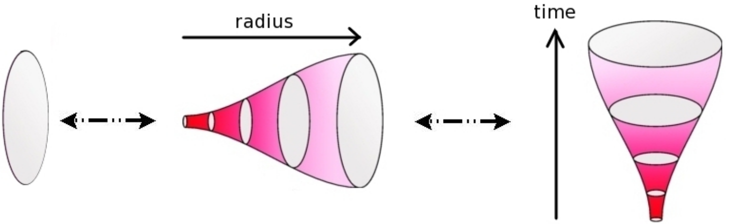
2. Holography for inflation using conformal perturbation theory.

   Bzowski, McFadden & Skenderis [1211.4550]

Introduction

Our holographic framework for cosmology is based on standard AdS/CFT plus the domain-wall/cosmology correspondence.

[PM & Skenderis '09-'11]



3d QFT

4d "domain-wall":

$$ds^2 = dr^2 + a^2(r)d\vec{x}^{\,2}$$

$$\varphi = \varphi(r)$$

4d cosmology:

$$ds^2 = -dt^2 + a^2(t)d\vec{x}^{\,2}$$

$$\varphi = \varphi(t)$$

Holographic formulae

The primordial power spectrum is given by

$$\Delta_S^2(q) = \frac{4}{\pi^4}\frac{1}{c(q)}$$

where $c(q)$ is the spectral density of the 2-point function $\langle TT\rangle$ in the dual QFT

$$\langle T(x)T(0)\rangle = \frac{\pi}{8}\int_0^\infty \mathrm{d}\rho\, c(\rho)\int \frac{\mathrm{d}^3 q}{(2\pi)^3}\frac{q^4}{q^2+\rho^2}e^{iq\cdot x}$$

$c(\rho)$ encodes the contribution of propagating intermediate states of mass ρ.

$$c(\rho) = \frac{16}{\pi^2}\frac{1}{\rho^3}\,\mathrm{Im}\,\langle T(q)T(-q)\rangle\Big|_{q^2=-\rho^2-i\epsilon}$$

Finding a small parameter

We want to compute the spectral density to find the holographic power spectrum.

For slow-roll inflation, however, the dual QFT is strongly coupled.

- Can't do perturbation theory in interaction strength.

Instead, we'll do perturbation theory in the dimension of an operator.

In the cosmology, this will be equivalent to expanding in the spectral tilt.

The dual QFT

We consider a dual QFT which is the deformation of a 3d Euclidean CFT by a nearly marginal scalar operator,

$$S = S_{CFT} + \varphi \int \mathrm{d}^3x \, \mathcal{O}(x),$$

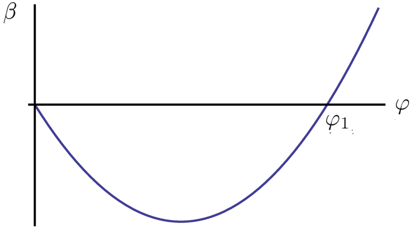
where $\mathcal{O}$ has scaling dimension $\Delta = 3 - \lambda$, with $0 < \lambda \ll 1$.

Correlators in the deformed theory are given by

$$\langle \mathcal{O}(x_1)\mathcal{O}(x_2) \rangle = \langle \mathcal{O}(x_1)\mathcal{O}(x_2) \exp\left(-\varphi \int \mathrm{d}^3z \, \mathcal{O}(z) \right) \rangle_{CFT}$$

β-function

$\mathcal{O}$ drives an RG flow to a new IR fixed point located at $\varphi_1 \sim \lambda \ll 1$.



$$\beta = -\lambda\varphi + B_2\varphi^2 + B_3\varphi^3 + O(\varphi^4)$$

Holographic power spectrum

Computing the spectral function and using the holographic formula we find:

$$\Delta_S^2(q) = \frac{H_*^2}{8\pi^2\epsilon_*}\Big[1 + 2b\eta_* + (3b^2 - 4 + \frac{5\pi^2}{12})\eta_*^2 + (-b^2 + \frac{\pi^2}{12})\delta_{2*} + O(\lambda^3)\Big].$$

$$b = 2 - \ln 2 - \gamma$$

Correct slow-roll power spectrum to second order for cosmology with $\epsilon_* \ll \eta_*$

cf. Gong & Stewart [astro-ph/0101225]

- QFT running coupling = inflaton at horizon crossing

$$\implies \quad \epsilon_* = \frac{1}{2}\beta^2 \sim \lambda^4, \qquad \eta_* = \beta' \sim \lambda, \qquad \delta_{2*} = \beta'^2 + \beta''\beta \sim \lambda^2.$$

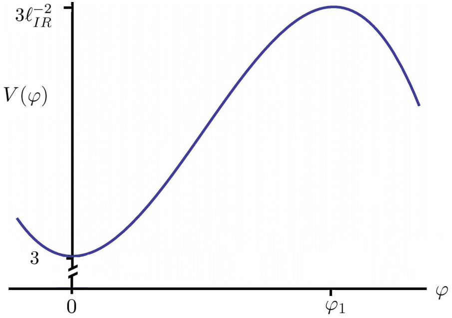
Inflaton potential

The inflaton potential also follows from the β-function:

$$V = \frac{1}{2}(6 - \beta^2)\exp(-\int_0^{\varphi} \beta d\varphi)$$

Hilltop model: we roll from $\varphi_1 \sim \lambda$ to the origin.

$\epsilon \ll \eta$ since two nearby extrema at each of which ϵ vanishes.



Non-Gaussianities

One can similarly compute cosmological 3-point functions holographically.

Form of bispectra fixed by perturbative breaking of conformal symmetry.

See [1211.4550] for results at leading order in λ for $\zeta\zeta\zeta$, $\zeta\zeta\gamma$, $\zeta\gamma\gamma$, etc.

Recover classic first-order slow-roll expressions (for $\epsilon_* \ll \eta_*$)

e.g., $\langle\zeta(q_1)\zeta(q_2)\zeta(q_3)\rangle = \eta_* \sum_{i<j}\langle\zeta(q_i)\zeta(-q_i)\rangle\langle\zeta(q_j)\zeta(-q_j)\rangle$

$$\langle\zeta(q_1)\zeta(q_2)\gamma^{(\pm)}(q_3)\rangle = \frac{H_*^4}{16\sqrt{2\epsilon*}}\frac{1}{q_3^2 a c^3}(-a^3 + ab + c)(a^3 - 4ab + 8c)$$

where $a = \sum q_i$, $b = \sum_{i<j} q_i q_j$, $c = q_1 q_2 q_3$.

Conclusions

We constructed slow-roll inflationary cosmology dual to 3d QFT which is deformation of a CFT by a nearly marginal scalar operator.

- ✦ Computed the power spectrum to second order in slow roll using the holographic formula $\Delta_S^2 = 4/\pi^4 c(q)$.
- ✦ Leading order non-Gaussianities also computed.

Striking test of holographic framework!

Further reading: [1308.0331] and [1211.4550]

Extensions

- Model reheating by introducing new operators changing fate of RG flow in the UV.

  Entropy perturbations $\leftrightarrow$ operator mixing under RG flow. Crossover behaviour now possible.

- Can we separate the fixed points further so that $\epsilon \sim \eta$ without losing control of the conformal perturbation theory?