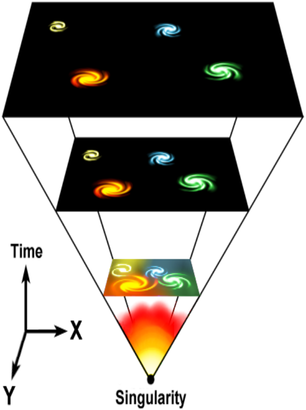
Vision session on "Cosmological Bootstrap"



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AdS/CFT meets carrollian & celestial holography
Edinburgh
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Models for non-geometric universe [McFadden, KS (2009)]

- General perturbative QFT involving massless scalars ϕ^I and gauge fields:

$$S = \frac{1}{g_{YM}^2} \int d^3x \mathrm{tr} \left(F_{ij}^2 + \frac{1}{2}(D\phi^I)^2 + \frac{\lambda}{4!}(\phi^I)^4 \right)$$

- All fields are massless and in the adjoint of $SU(N)$, λ is a dimensionless coupling while g_{YM}^2 has mass dimension 1.
- Mostly fermionic models are ruled out by CMB data.

Predictions

- For this class of theories, the 2-point function of the energy-momentum tensor at large N takes the form,

$$\langle T(q)T(-q)\rangle = N^2 q^3 f(g_{\text{eff}}^2),$$

where $g_{\text{eff}}^2 = g_{\text{YM}}^2 N/q$ is the effective dimensionless 't Hooft coupling and $f(g_{\text{eff}}^2)$ is a general function of g_{eff}^2.

- Scalar power-spectrum:

$$\Delta_{\mathcal{R}}^2 = \frac{1}{16\pi^2 N^2} \frac{1}{f(g_{\text{eff}}^2)}$$

- Smallness of perturbations ➠ N is very large.
- Nearly scale invariant spectrum ➠ $f(g_{\text{eff}}^2)$ is nearly constant.

- Universal predictions for non-gausianities.

Perturbative results

- Perturbative QFT at 2-loops,

$$f(g_{\rm eff}^2) = f_0(1 - f_1 g_{\rm eff}^2 \log g_{\rm eff}^2 + f_2 g_{\rm eff}^2 + \alpha_2 \log \frac{g_{YM}^2}{\mu_{IR}} + O[g_{\rm eff}^4]).$$

  where f_0, f_1, f_2, α_2 are constants that depend on the field content etc. μ_{IR} is an IR cut-off.

- For comparison if the dual QFT is a CFT perturbed by a nearly marginal operator:

$$f \sim q^{-(3-\Delta)},$$

  where Δ is the dimension of a nearly marginal operator, $\Delta \lesssim 3$. This corresponds to slow-roll inflation.

Results

- The fit to data implies that $g_{eff}^2 = g_{YM}^2 N/q$ is very small for all scales seen in CMB, except at very low multipoles, justifying *a posteriori* the use of perturbation theory.

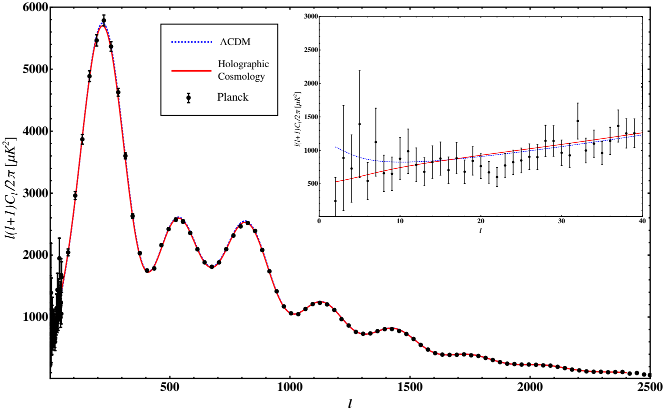
- For $l < 30$ the model becomes non-perturbative and one cannot trust the perturbative prediction.

- Goodness of fit ($l > 30$)

	HC	ΛCDM
χ^2	824.0	824.5

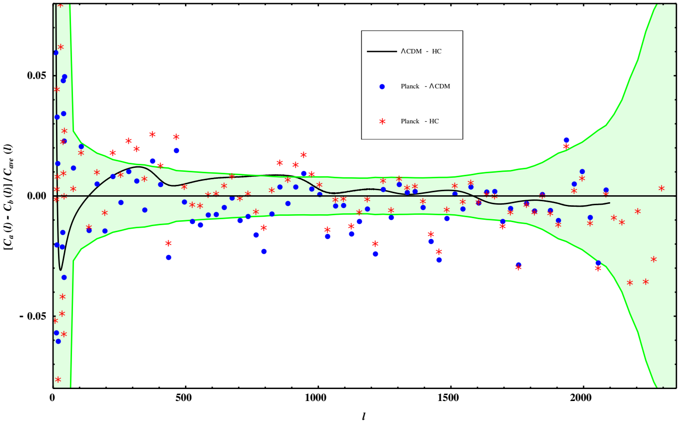
  The difference in χ^2 indicate that the models are less than 1σ apart.

Fit to CMB



[Afshordi, Coriano, Delle Rose, Gould, KS, PRL2017] [Afshordi, Gould, KS, PRD2017]

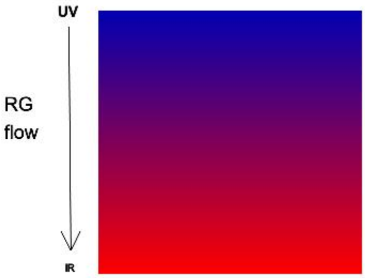
Fit to CMB – residuals

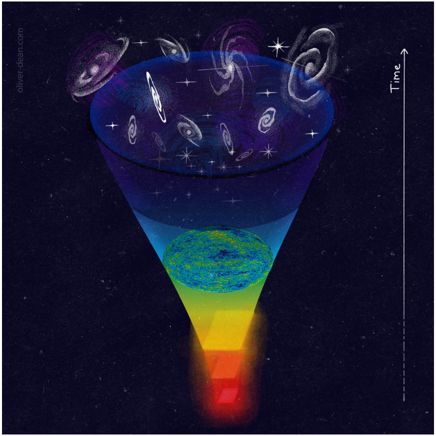


[Afshordi, Coriano, Delle Rose, Gould, KS, PRL2017] [Afshordi, Gould, KS, PRD2017]

The initial singularity

- In holographic cosmology, time evolution is inverse RG flow and the initial singularity is mapped to the IR of the QFT.





Singularity resolution

- Massless super-renormalizable theories have severe IR singularities in perturbation theory.
- If the IR singularities persist non-perturbatively such theories are non-predictive.
- It was argued by [Jackiw,Templeton (1981)][Appelquist, Pisarski(1981)] that these type of theories are non-perturbative IR finite:

g_{YM}^2 effectively acts as an IR regulator.

- As time evolution is inverse RG flow, this corresponds to the resolution of the initial singularity.

A simple model

- A non-minimally coupled massless scalar field in the adjoint of $SU(N)$ with ϕ^4 self-interaction

$$S = \frac{2}{g_{YM}^2} \int d^3x \mathrm{Tr} \left(\frac{1}{2} (\partial_\mu \phi)^2 + \frac{\lambda}{4!} \phi^4 \right),$$

and energy momentum tensor

$$T_{ij} = \frac{2}{g_{YM}^2} \mathrm{Tr} \left(\partial_i \phi \partial_j \phi - \delta_{ij} \left(\frac{1}{2} (\partial \phi)^2 + \frac{\lambda}{4!} \phi^4 \right) + \xi (\delta_{ij} \Box - \partial_i \partial_j) \phi^2 \right)$$

- The perturbative answer to 2-loops for the two-point function of the energy-momentum tensor was worked out in [Coriano, Delle Rose, KS (2020)].

Does this theory exists?

- To answer this question one needs a non-perturbative formulation.
- Evaluate the path integral using Lattice methods.
- Unless the IR infinities cancel, the critical theory does not exist.

- We determined non-perturbatively using lattice QFT that the critical theory exists.
- The singularity is resolved as anticipated, with $\mu_{IR} \sim g_{YM}^2$.

  [LatCos collaboration (L. Del Debbio, A. Jüttner, B. Kitching-Morley, J. Lee, KS, Portelli, H. Rocha) PRL (2020)]

Observable signatures of singularity resolution?

- We need to compute the 2-point function of the energy-momentum using Lattice QFT.
- Compare with cosmological data.

- 2-point function of scalar $\langle \mathrm{Tr}\,\phi^2 \mathrm{Tr}\,\phi^2 \rangle$ *[preliminary results]*