YTF10: Lattice Holographic Cosmology

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Image credit: ESA and the Planck Collaboration

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In this talk...

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The Faults in Our Universe?

- Flatness problem:
  - $\Omega_0 = 1.0023^{+0.0056}_{-0.0054}$ from Planck 2015 [1]
  - Very fine-tuned initial energy density required?
  - Density diverges from critical with cosmic time...
  - Closer than 1 in 10^{62} to Ω_c at Big Bang!!
- Horizon Problem:
  - In CMB and galaxy surveys: Isotropy
  - Cosmological Principle: Homogeneity
  - At CMB, causal sphere was 9×10^5ly $\rightarrow 1^o$ in sky today
  - Two causally disconnected regions are homogeneous?! $(2.73K)$

The Faults in Our Model!

- BBT couldn't solve these.
- Alan Guth submitted "Inflationary universe: A possible solution to the horizon and flatness problems" in 1980 [2]
- Suggested a period of supercooling in early universe ($10^{-36}s \rightarrow 10^{-32}s$) would lead to rapid expansion (now calculated at around 60 e-folds)

Figure: A happy Prof. Guth. Credit: MIT

In this talk...

Solved Problems?

- Inflation became widely accepted scenario
- Further work including that by Andrei Linde (chaotic inflation) and Paul Steinhardt (eternal inflation)

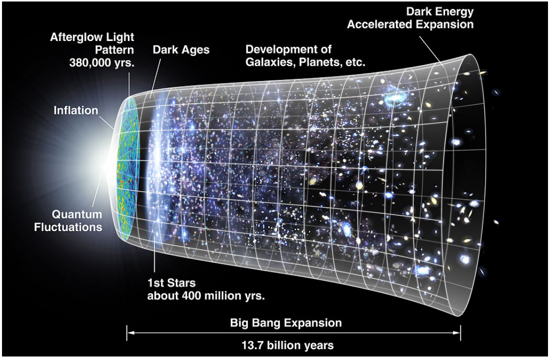


Figure: Typical illustration of universe timeline. Credit: NASA

New problems

- Unknown mechanism underlying inflation
- Inflation is not falsifiable

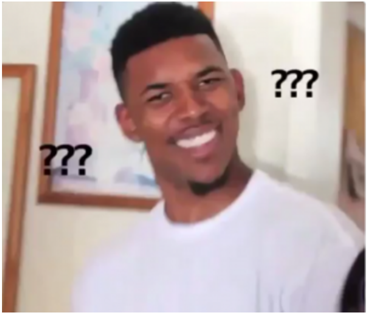


Figure: A popular meme

In this talk...

Motivation for HC

- Theory of inflation based on gravity coupled to matter around FLRW background
- At very early time, perturbative treatment expected to break down due to increasingly large curvature
- Would thus require theory of quantum gravity!

Motivation for HC

- Quantum gravity expected to be holographic.
- Reduce bulk physics of QG to a QFT with no gravity in one dimension fewer
- Holography can let us predict cosmological observations!
- Bonus: Principle of holographic duality allows models with weakly coupled QFTs

HC Details

- McFadden and Skenderis [3] introduced a class of models based on 3D super-renormalisable QFTs.
- Found that these universally predicted a scalar power spectrum of form:

$$\Delta_0^2(q) = \frac{\Delta_0^2}{1 + (gq_*/q)ln|q/\beta gq_*| + \mathcal{O}(gq_*/g)^2} \tag{1}$$

where g is related to the coupling constant of the theory and β depends on the loop calculations.

ΛCDM

- Widely regarded as standard model of cosmology
- Simple version has 6 independent parameters
- Expanded by inflationary scenarios if so chosen
- Predicts the power spectrum of CMB:

$$\Delta_R^2(q) = \Delta_0^2(q_*)\left(\frac{q}{q_*}\right)^{n_s-1} \quad (2)$$

Parameter	Value
$\Omega_b h^2$	0.02230 ± 0.00014
$\Omega_c h^2$	0.1188 ± 0.0010
$100\theta_{MC}$	1.0415 ± 0.0006
n_s	$0.9667 \pm .0040$
Δ_R^2	$2.441^{+0.088}_{-0.092} \times 10^{-9}$
τ	0.066 ± 0.012

Table: 6 parameters for the ΛCDM model

Competitive Models

- Afshordi et al. [4] compared how well the HC power spectrum 1 fitted the Planck data against ΛCDM 2
- Both models within 2σ of data, however large difference between them at low ($l \lessapprox 30$) multipole

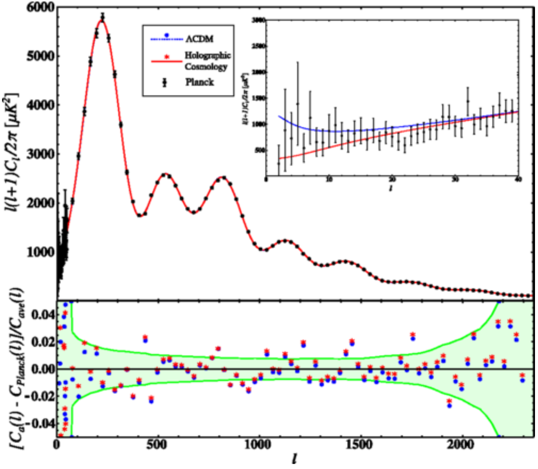


Figure: TT spectrum for both ΛCDM and HC against 2015 Planck data. [4]

Conclusions from HC

	HC		ΛCDM	
	best fit	2σ range	best fit	2σ range
$\Omega_b h^2$	0.2217	0.2215 ± 0.00021	0.02227	0.0225 ± 0.00020
$\Omega_c h^2$	0.1173	0.1172 ± 0.0012	0.1185	0.1186 ± 0.0012
$100\theta_{MC}$	1.04112	1.04115 ± 0.00042	1.04103	1.04104 ± 0.00042
τ	0.081	0.082 ± 0.013	0.067	0.067 ± 0.013
$10^9 \Delta_0^2$	2.126	2.126 ± 0.058	2.143	2.143 ± 0.052
n_s	–	–	0.9682	0.9677 ± 0.0045
g	-0.0070	$-0.0074^{+0.0014}_{-0.0013}$	–	–
$ln\beta$	0.88	$0.87^{+0.19}_{-0.24}$	–	–
χ^2	11324.5		11319.9	

Table: Parameter comparison between HC and ΛCDM from Afshordi, Gould & Skenderis 2017. All common parameters within 1σ of each other. [5]

So what's the problem?

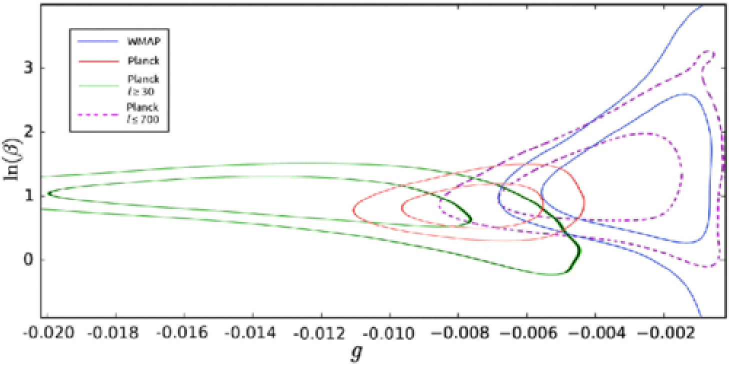
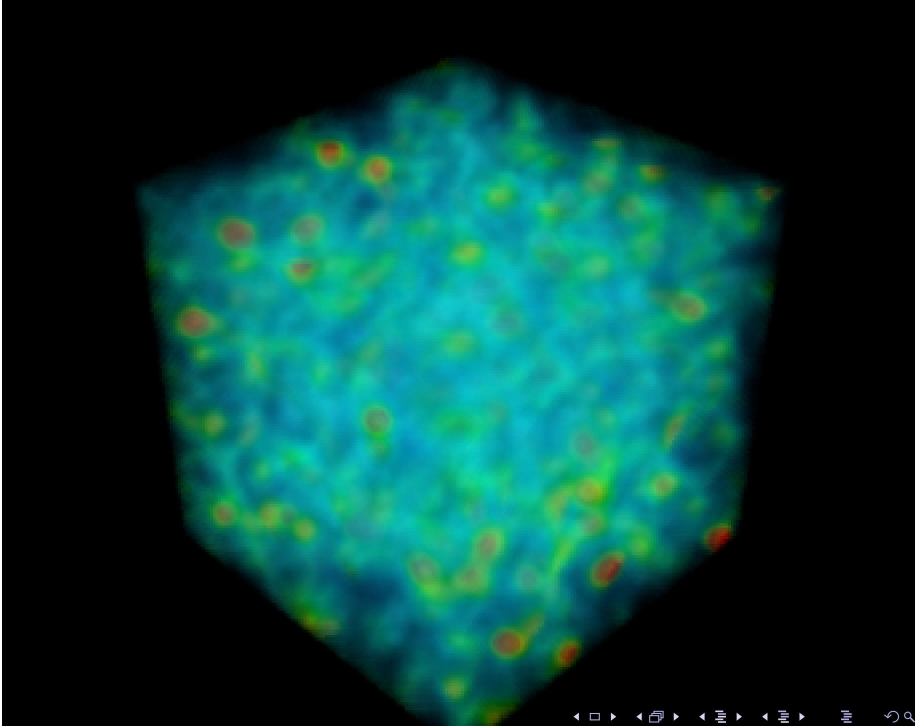


Figure: Values of g and $ln|\beta|$ constrained by WMAP and Planck 2015 data. g is pushed lower as data is restricted to low multipoles...



In this talk...

Pathway to LHC's (not that one) goal...

- So we are currently using the powers of lattice to model the low multipole region
- This process is going to involve a large number of steps starting from lots of high statistic simulations and culminating with final models making falsifiable predictions against the CMB data once again

Current Progress

- No papers yet...
- Locating the mass parameter in finite lattice simulations which translates to a massless renormalised theory ✓
- Using computational techniques to increase information yield from MCMC simulations ✓
- Using numerical methods to remove finite volume effects to find true critical mass point...
- Begin calculating energy-momentum tensors (Coming soon...)

In this talk...

Summary

- (VERY) brief history lesson
- What drives us to find what drives inflation
- This is a multi-disciplinary collaboration
- In early stages but making promising progress

Roll credits...

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[1] P. A. R. Ade *et al.*, "<i>Planck</i> 2015 results," *Astronomy & Astrophysics*, vol. 594, p. A13, oct 2016.

[2] A. H. Guth, "Inflationary universe: A possible solution to the horizon and flatness problems," *Physical Review D*, vol. 23, pp. 347–356, jan 1981.

[3] P. McFadden and K. Skenderis, "Holography for cosmology," *Physical Review D*, vol. 81, p. 021301, jan 2010.

[4] N. Afshordi, C. Corianò, L. Delle Rose, E. Gould, and K. Skenderis, "From Planck Data to Planck Era: Observational Tests of Holographic Cosmology," *Physical Review Letters*, vol. 118, p. 041301, jan 2017.

[5] N. Afshordi, E. Gould, and K. Skenderis, "Constraining holographic cosmology using Planck data," mar 2017.