A smooth Exit from Eternal Inflation

arxiv:1707.0772 (JHEP 04 (2018))

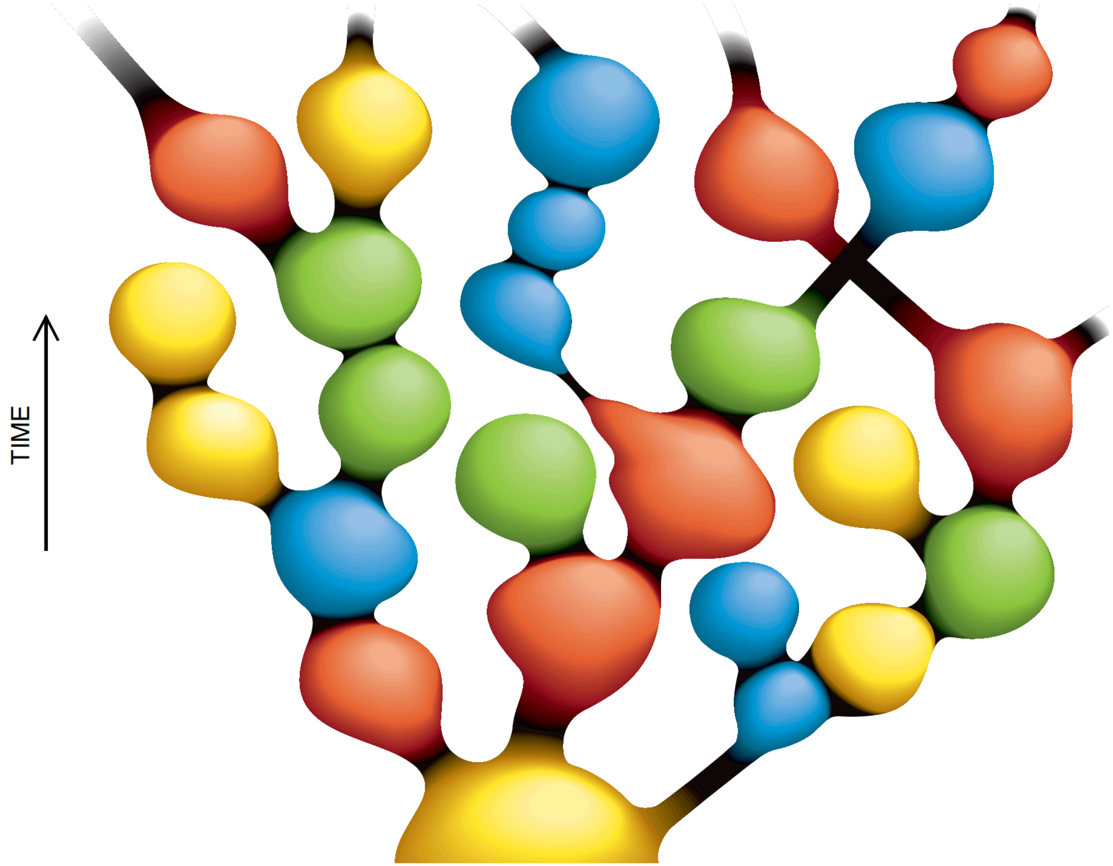
w/ Stephen Hawking

MG 15

Thomas Hertog

Institute for Theoretical Physics
KU Leuven

Eternal Inflation



[A. Linde]

A mosaic of pocket universes

A smooth exit from eternal inflation?

S.W. Hawking[a] **and Thomas Hertog**[b]

[a] *DAMTP, CMS,*
Wilberforce Road, CB3 0WA Cambridge, U.K.

[b] *Institute for Theoretical Physics, University of Leuven,*
Celestijnenlaan 200D, 3001 Leuven, Belgium

E-mail: S.W.Hawking@damtp.cam.ac.uk, Thomas.Hertog@kuleuven.be

Abstract: The usual theory of inflation breaks down in eternal inflation. We derive a dual description of eternal inflation in terms of a deformed Euclidean CFT located at the threshold of eternal inflation. The partition function gives the amplitude of different geometries of the threshold surface in the no-boundary state. Its local and global behavior in dual toy models shows that the amplitude is low for surfaces which are not nearly conformal to the round three-sphere and essentially zero for surfaces with negative curvature. Based on this we conjecture that the exit from eternal inflation does not produce an infinite fractal-like multiverse, but is finite and reasonably smooth.

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ASTROPHYSICAL COSMOLOGY

PROCEEDINGS OF THE STUDY WEEK ON COSMOLOGY AND FUNDAMENTAL PHYSICS

September 28 - October 2, 1981

EDITED BY

H. A. BRÜCK, G. V. COYNE AND M. S. LONGAIR

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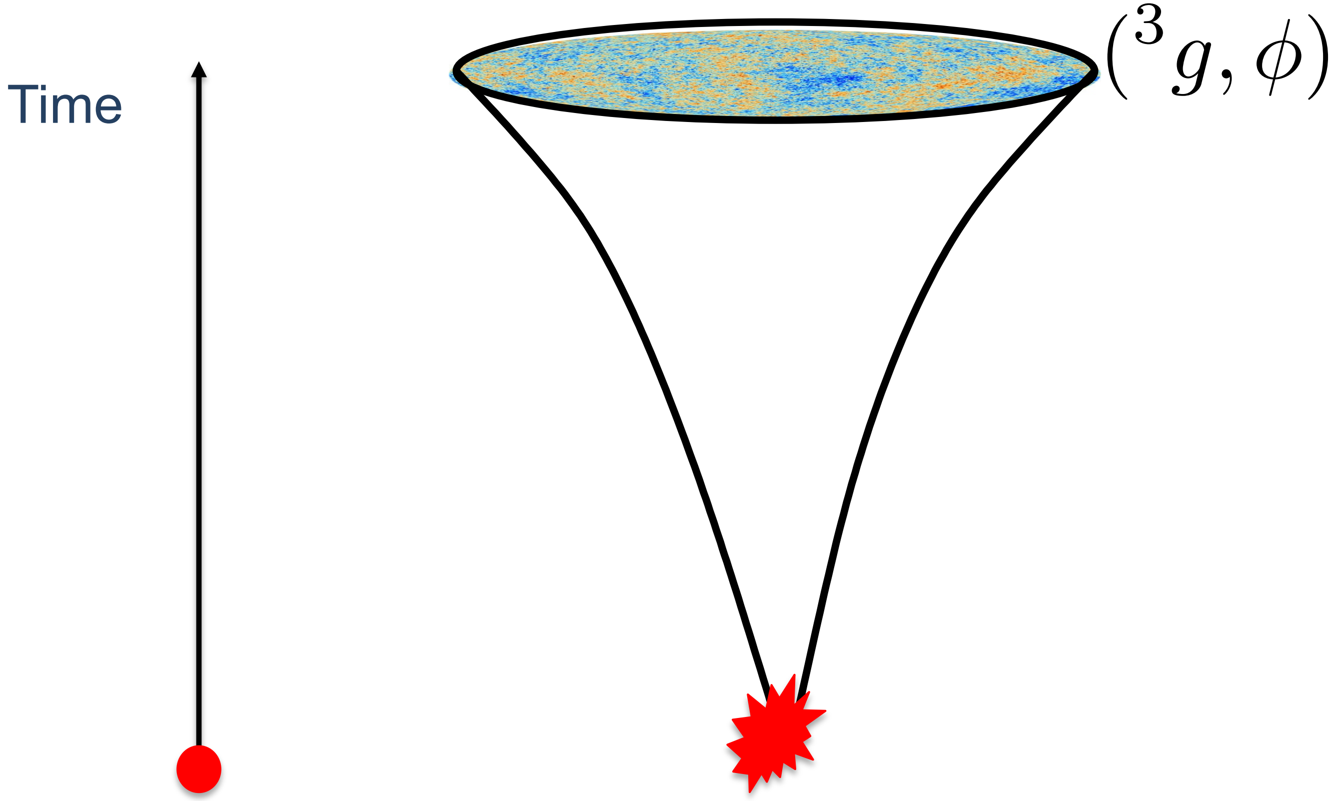
MCMLXXXII

No-Boundary Proposal

"The boundary condition of the universe is that it has no boundary."

[Hawking, Pont. Ac. Sci.1982]

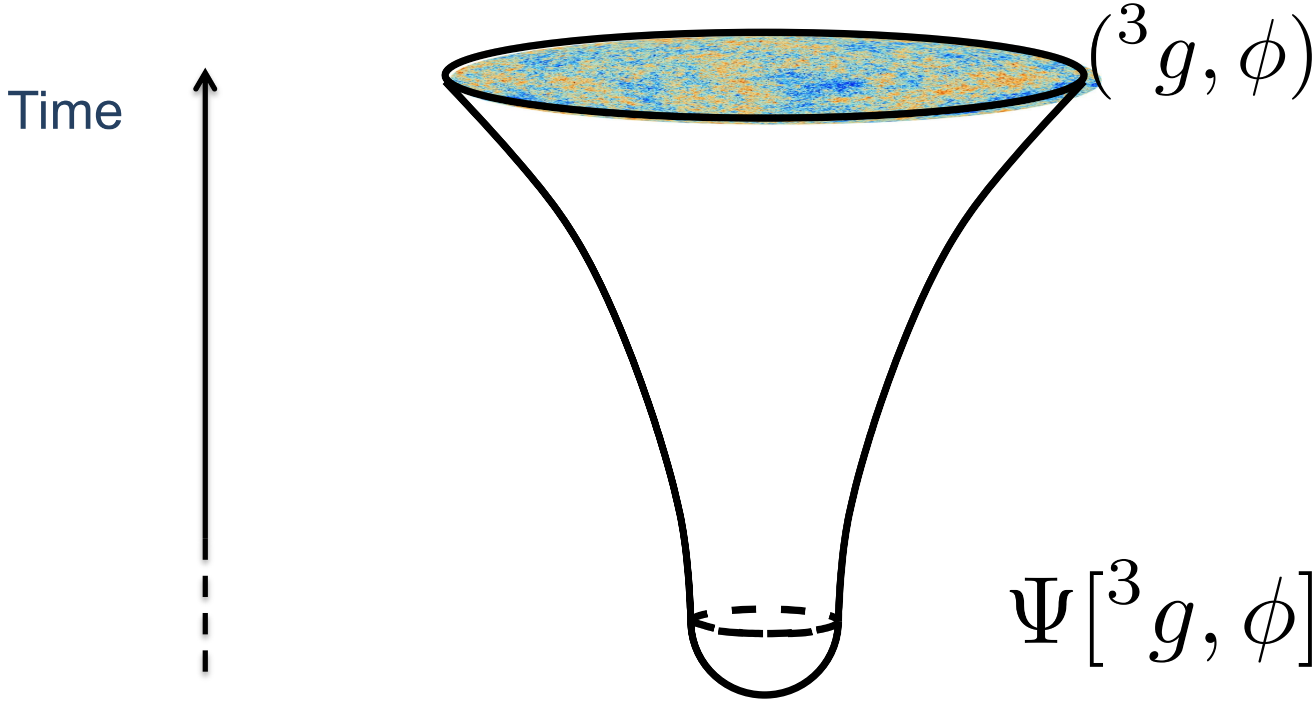


Classical singularity

No-Boundary Proposal

"The boundary condition of the universe is that it has no boundary."

[Hawking, Pont. Ac. Sci.1982]

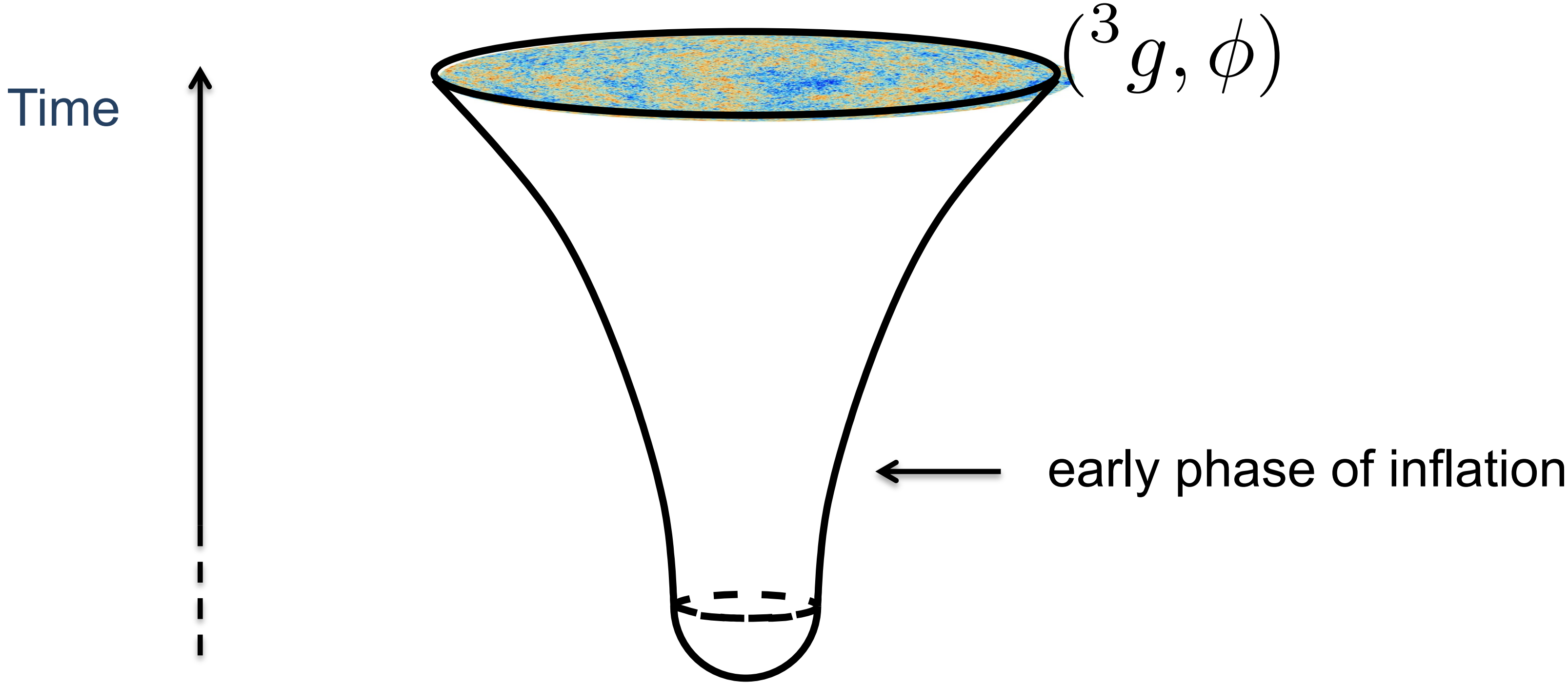


Quantum smoothness

No-Boundary Proposal

"The boundary condition of the universe is that it has no boundary."

[Hartle and Hawking, PRD 1983]



$$\Psi_{NB}[^3g, \phi] \sim \exp\left(-I_E[^3g, \phi]/\hbar\right) \sim Ae^{iS/\hbar}$$

A measure on inflation

[Hartle, Hawking, TH, PRL 2008]

$$\Psi_{NB}[{}^3g, \phi] \sim \exp\left(-I_E[{}^3g, \phi]/\hbar\right) \sim Ae^{iS/\hbar}$$

"The no-boundary wave function is peaked around inflationary universes. It explains why inflation started in the first place, with perturbations initially in their ground state."

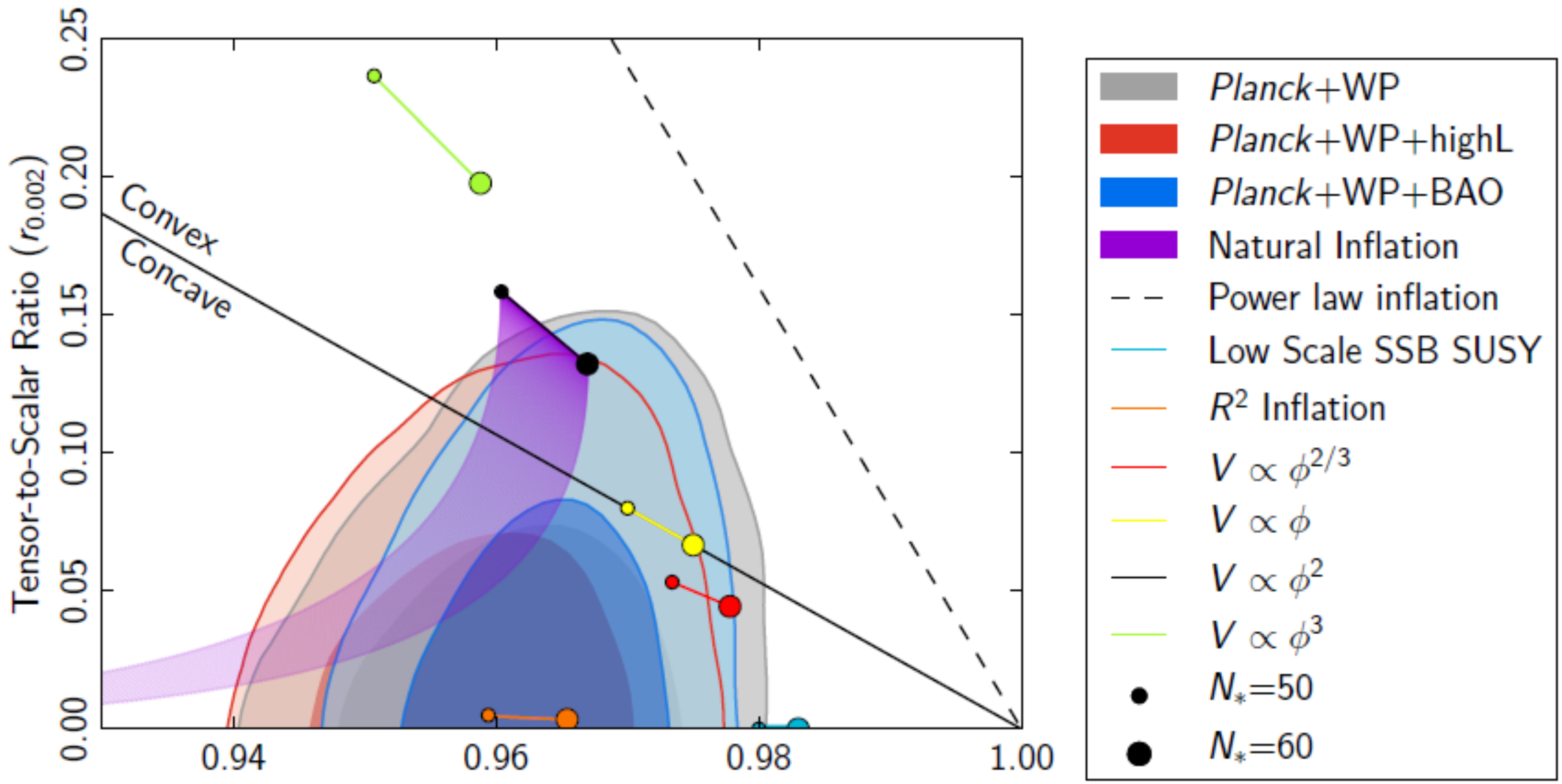
$$P_{histories} \sim A^2[{}^3g, \phi]$$

A Prior for Planck

[TH, JCAP 2013]

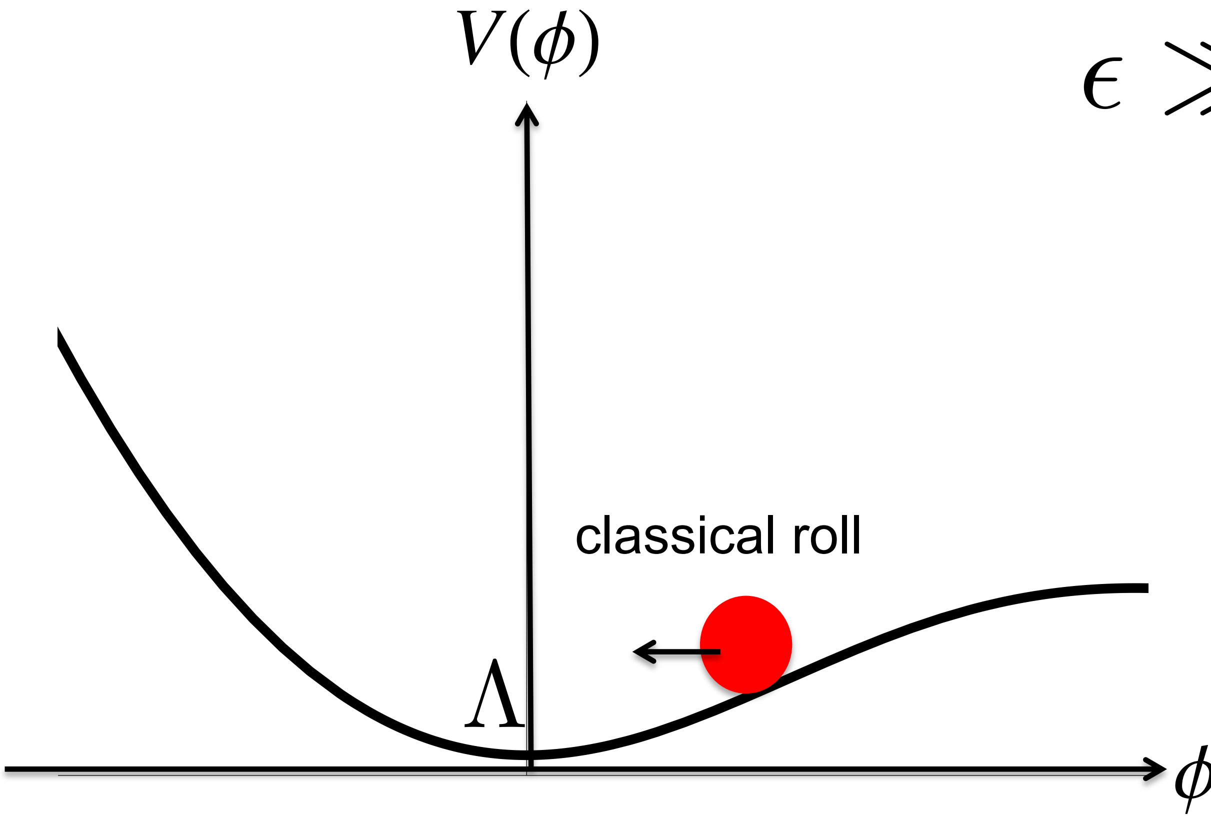
[Planck XXII 2013]

"Landscape of potentials"



$|\Psi|^2 \longrightarrow$ *relative weighting of models* $\longrightarrow$ *sharp predictions*

Slow roll inflation

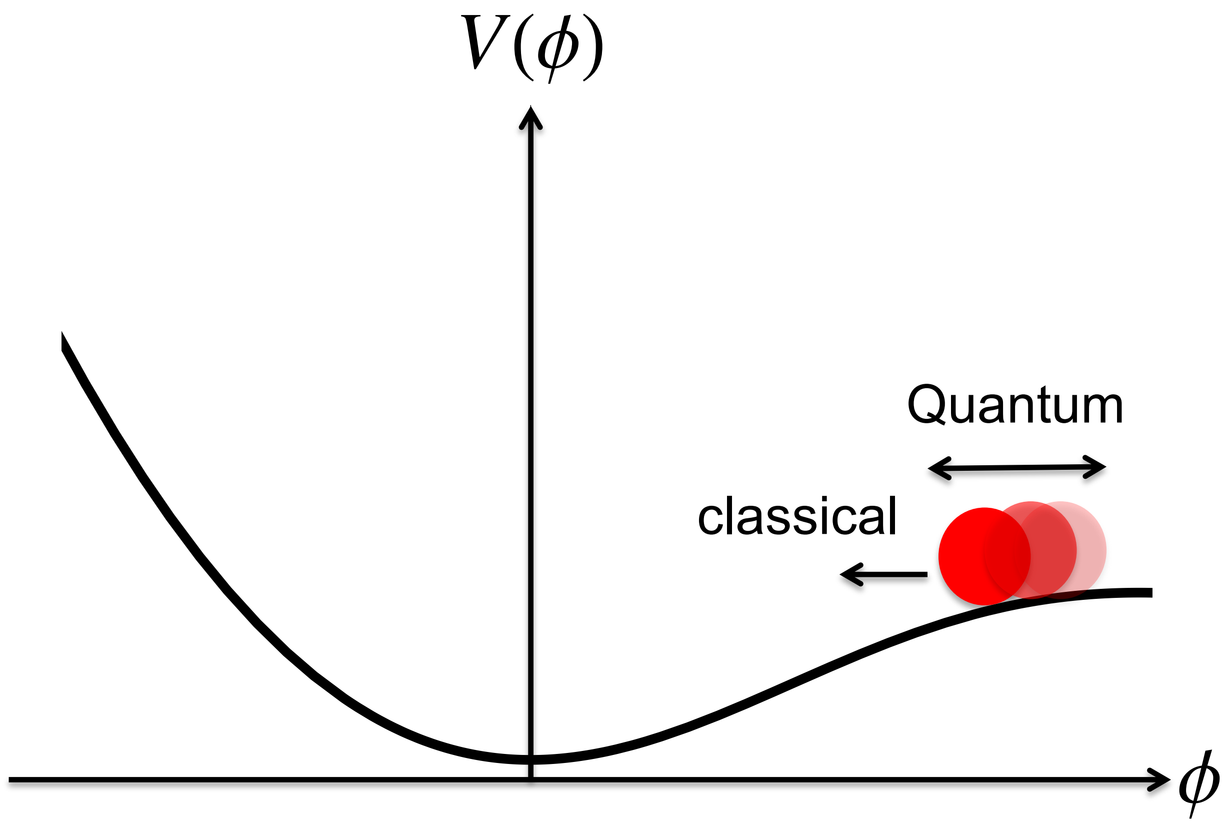


$$\epsilon \gg H^2$$

$$\Psi[\zeta] \propto \prod_n \exp\left(-\frac{\epsilon}{H^2} n^3 \zeta_n^2\right)$$

Eternal inflation

$$\epsilon \leq H^2$$



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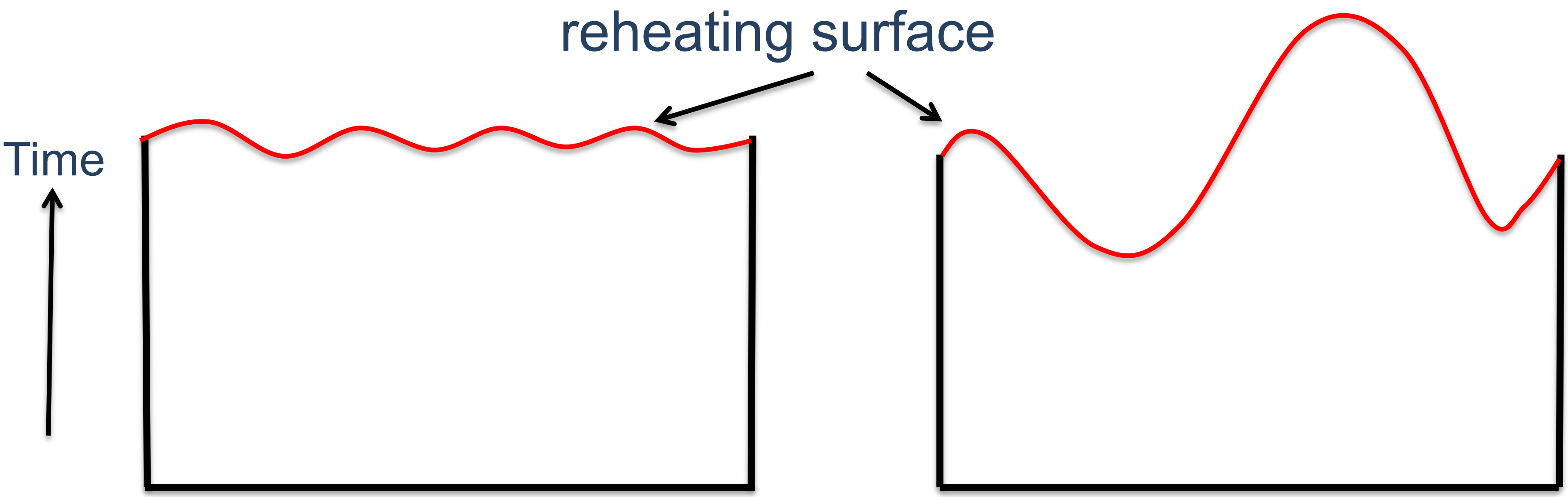
Eternal Inflation



Slow roll

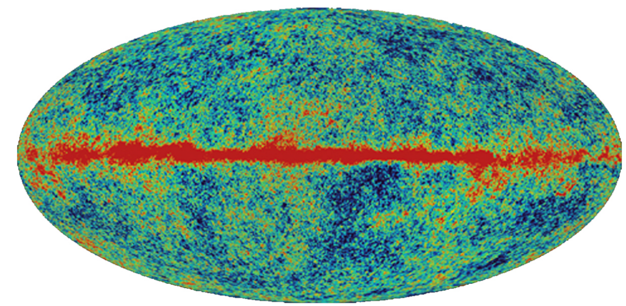
Eternal inflation

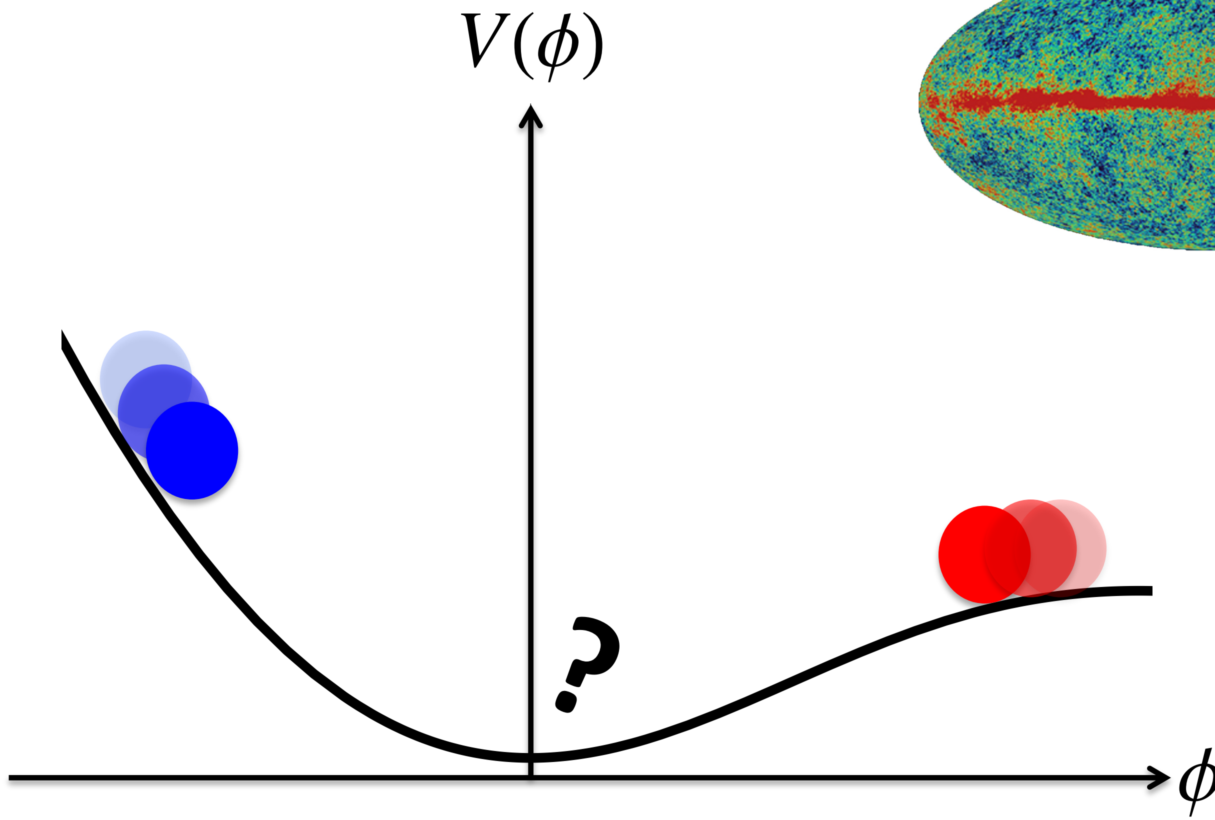
Ψ narrowly peaked

Ψ broadly distributed

No Prior for Planck?

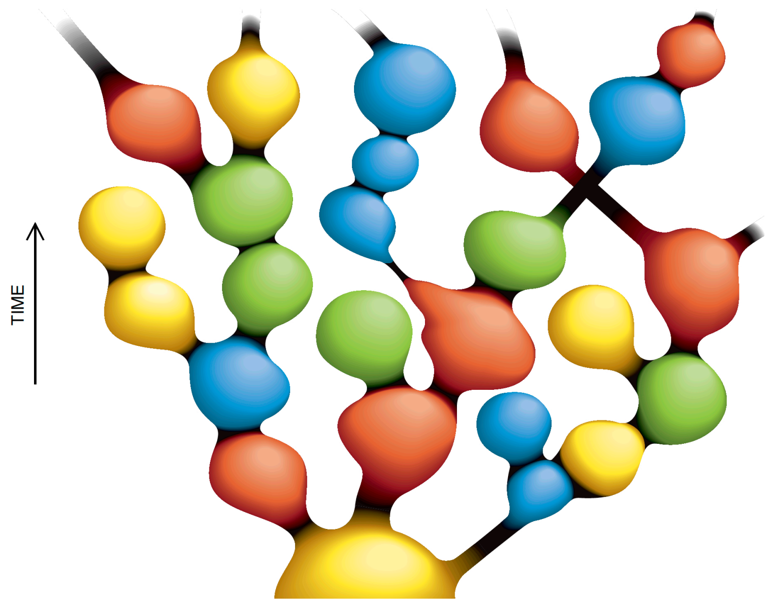
[TH, JCAP 2013]





Does Ψ spread out evenly over all possible inflationary histories?

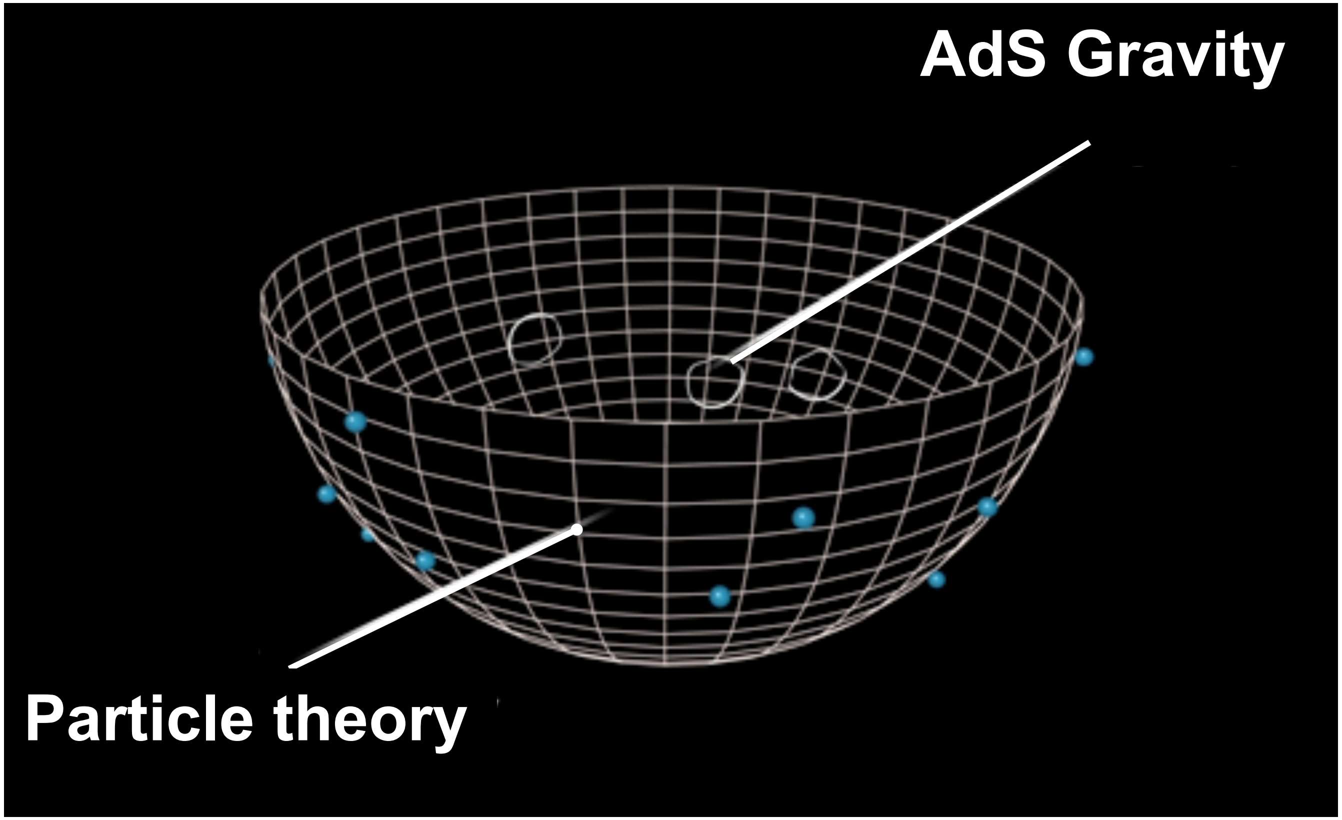
Eternal Inflation



Does Ψ spread out evenly over all possible inflationary histories?

Holography

[Maldacena 1997; Witten 1998]



Holographic Cosmology

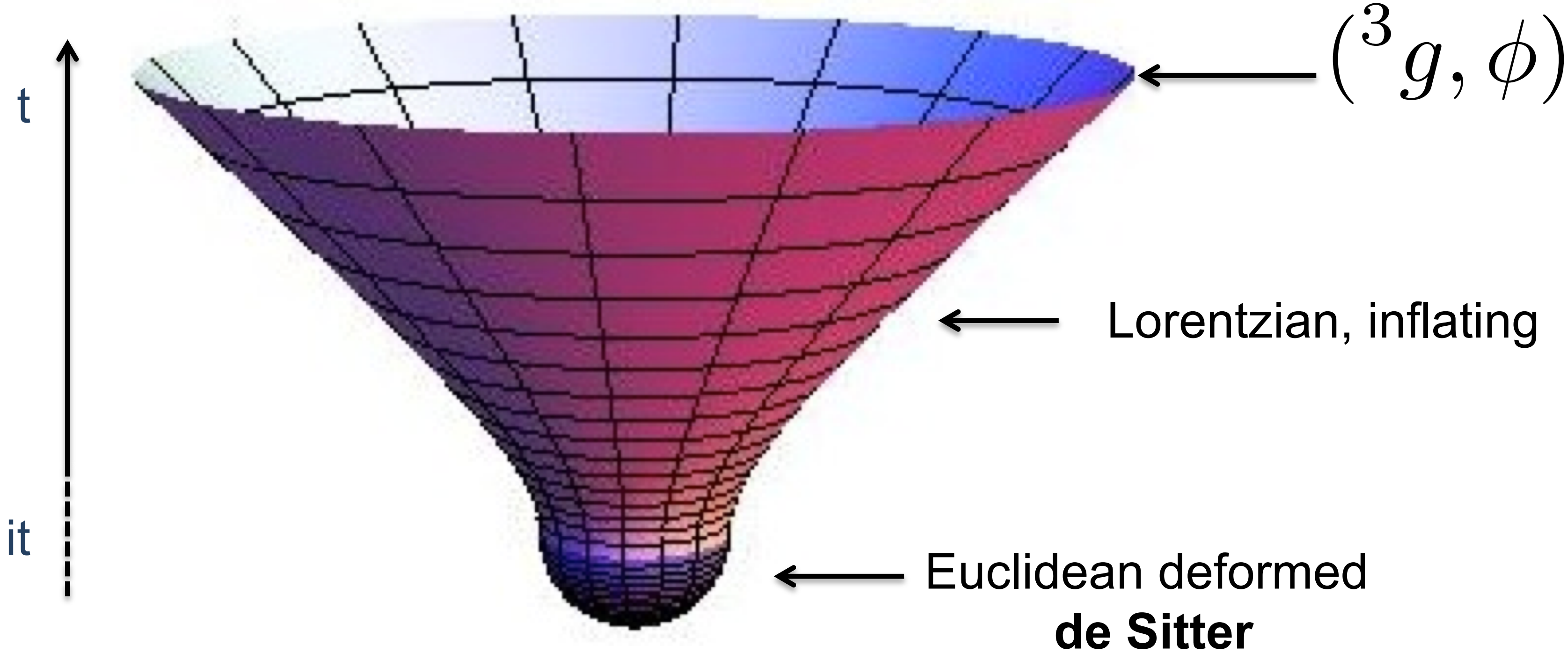
[Horowitz & Maldacena '04; Hartle & TH '11; Anninos, Hartman, Strominger '12;..]

$$\Psi_{NB}[^3g, \phi] \longleftrightarrow Z_{QFT}[^3\tilde{g}, \tilde{\phi}]$$

Can we use holography to define and evaluate the no-boundary wave function in eternal inflation?

Holographic Cosmology

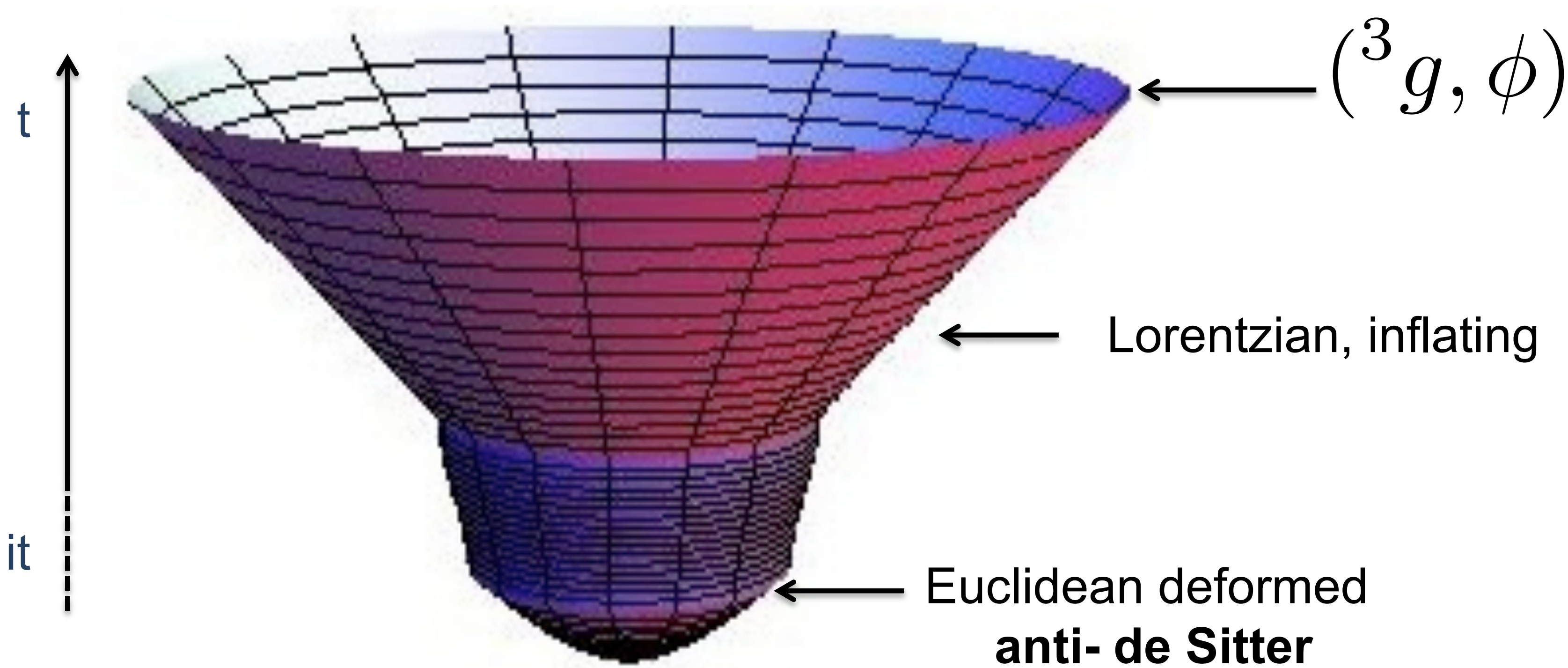
[Hartle & TH, JHEP 2011]



$$\Psi_{NB}[^3g, \phi] \sim A(^3g, \phi) \exp(iS[^3g, \phi]/\hbar)$$

Holographic Cosmology

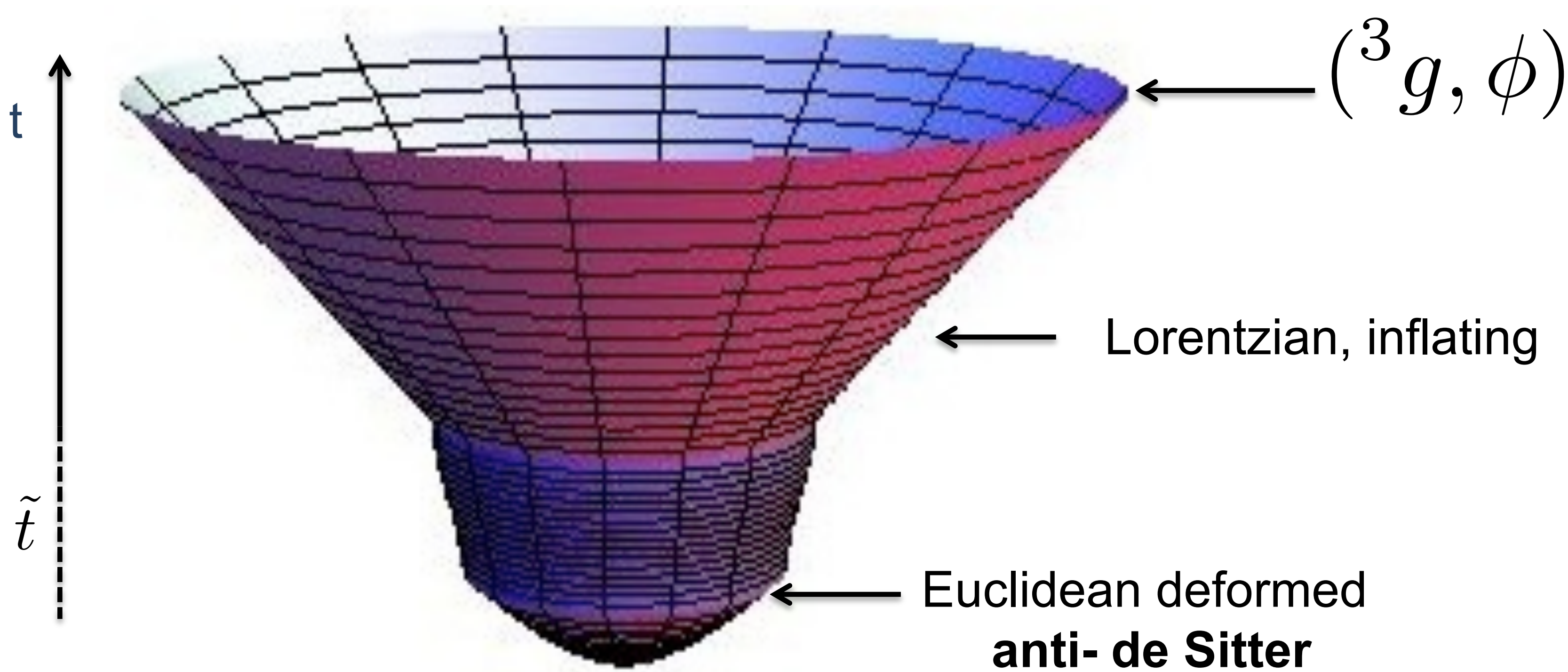
[Hartle & TH, JHEP 2011]



$$\Psi_{NB}[{}^3g, \phi] \sim A({}^3g, \phi) \exp(iS[{}^3g, \phi]/\hbar)$$

Holographic Cosmology

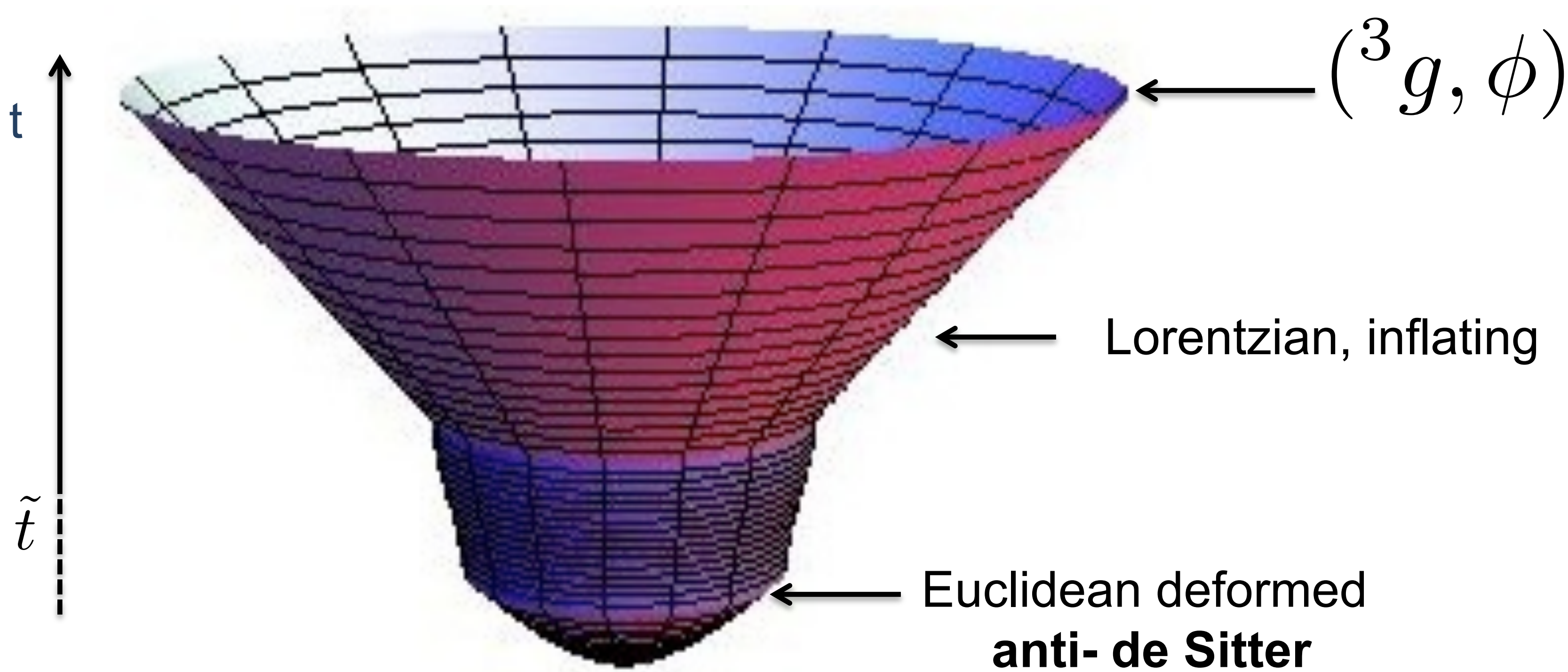
[Hartle & TH, JHEP 2011]



Ψ "connects" Euclidean AdS and Lorentzian de Sitter

Holographic Cosmology

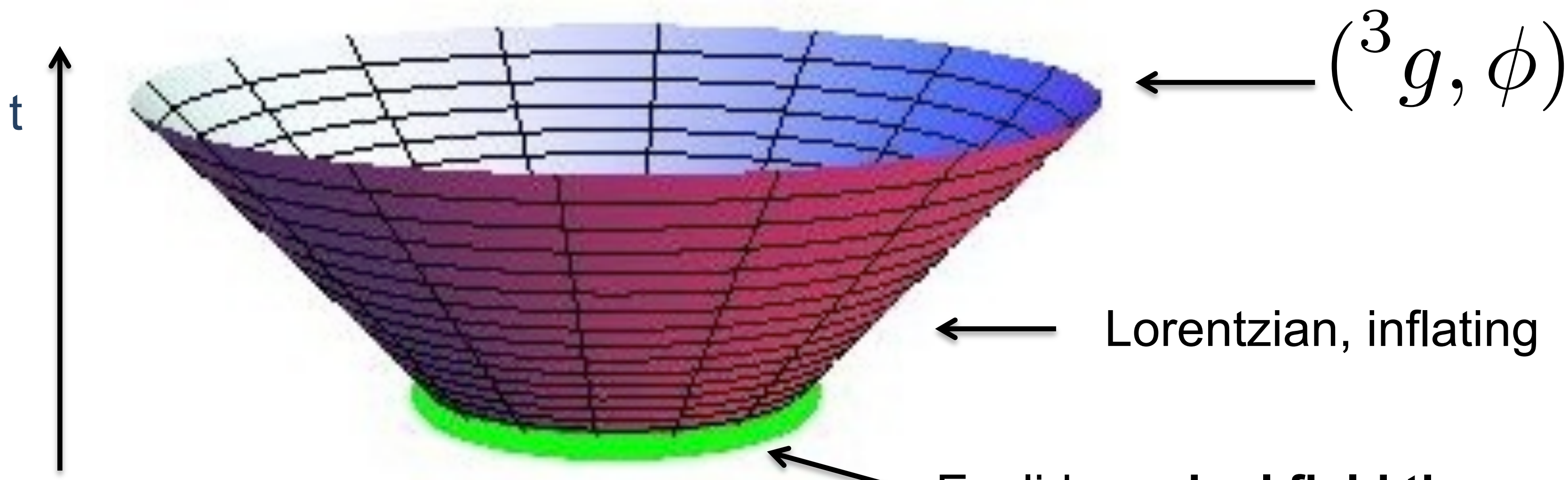
[Hartle & TH, JHEP 2011]



$$A({}^3g, \phi) = \exp(I^{reg}_{AdS}[{}^3\tilde{g}, \tilde{\phi}]/\hbar)$$

Holographic Cosmology

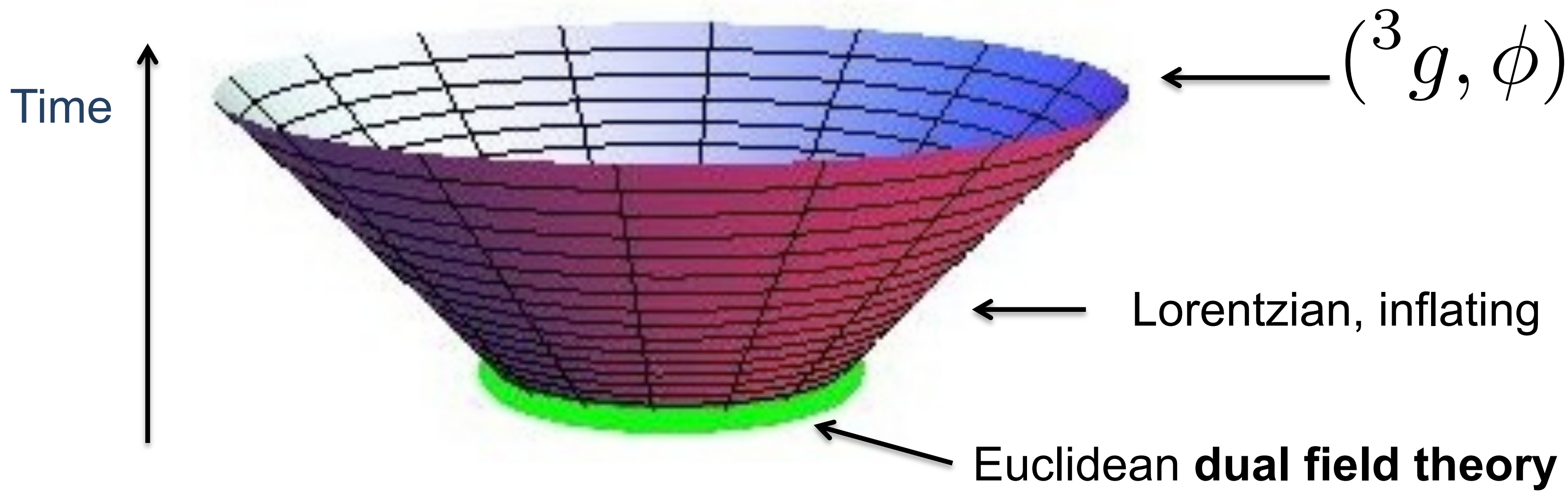
[Hartle & TH, JHEP 2011]



$$Z_{QFT}[{}^3\tilde{g}, \tilde{\phi}] \to A({}^3g, \phi)$$

Holographic Cosmology

[Hartle & TH, JHEP 2011]



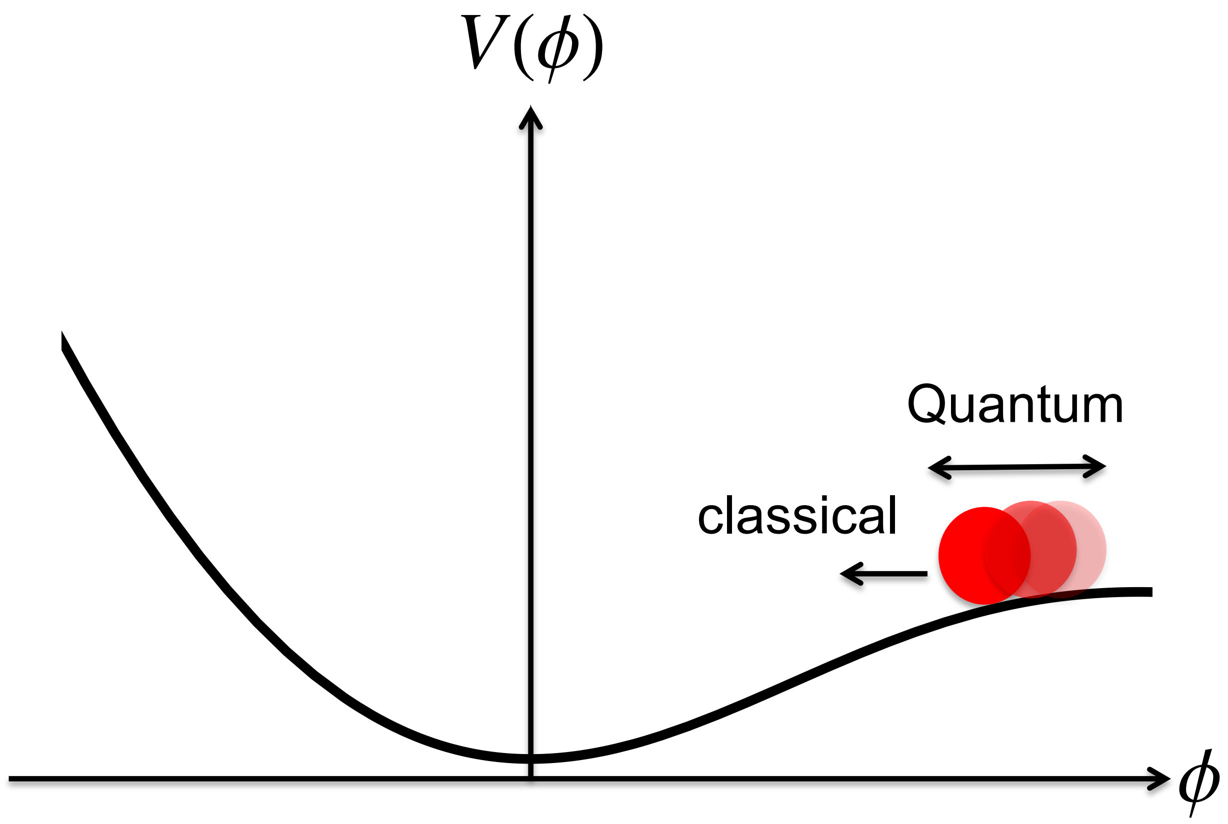
$$Z_{QFT}[{}^3\tilde{g}, \tilde{\phi}] \rightarrow A({}^3g, \phi)$$

The partition function specifies the amplitude of different initial geometries ^{3}g and field configurations.

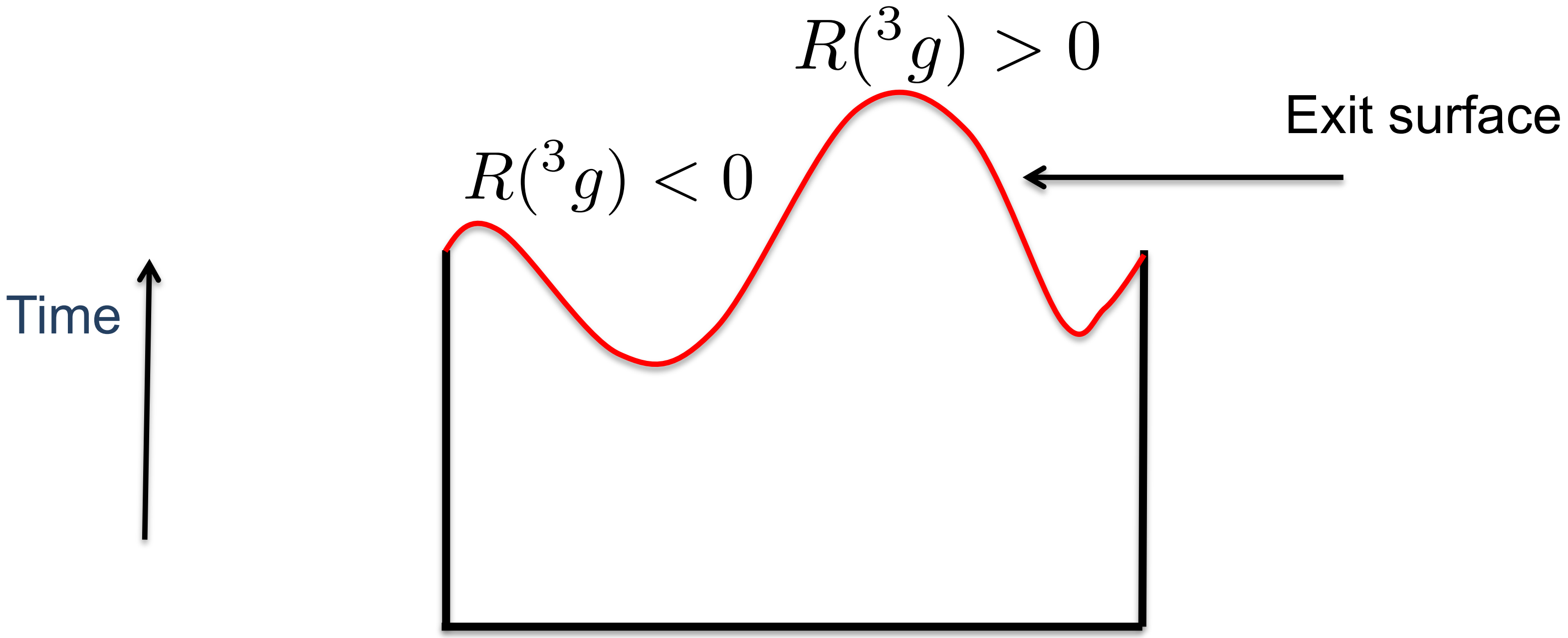
Revisit eternal inflation; dual field theory at exit eternal inflation

Toy model

[Hawking & TH, JHEP 2018]

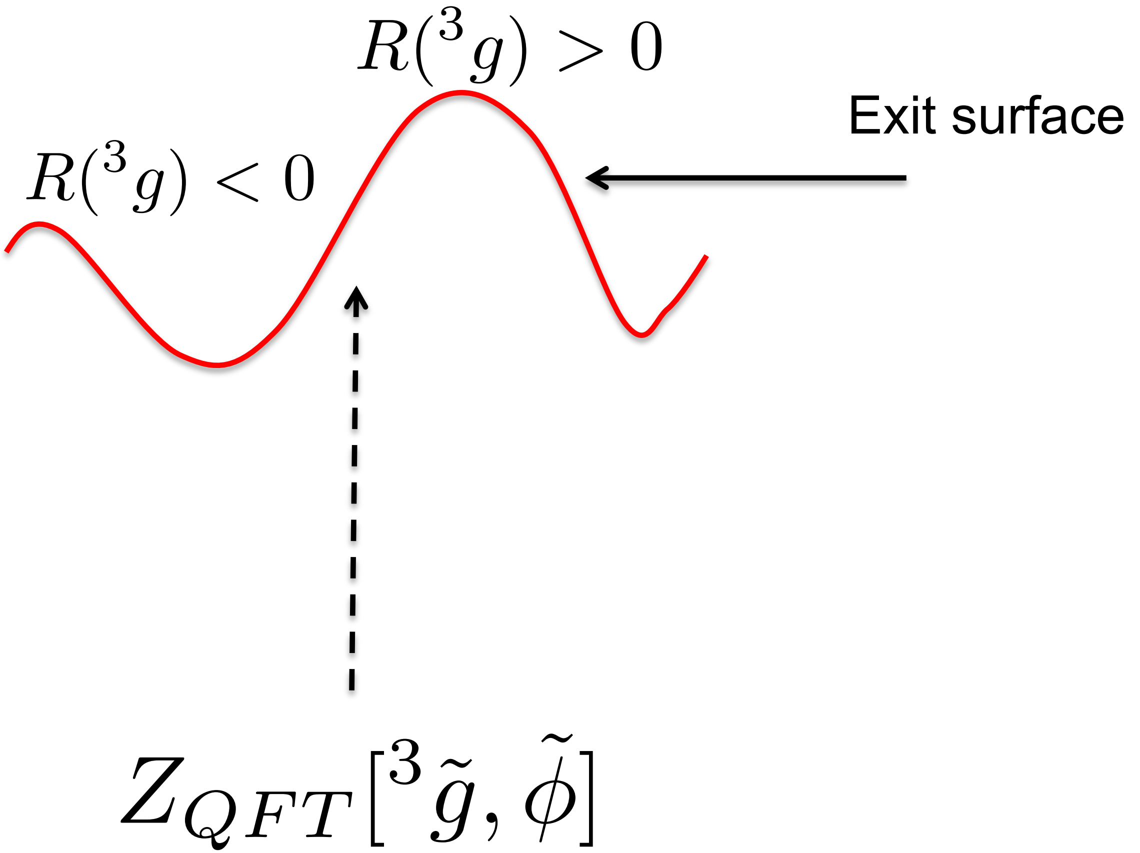


Toy model



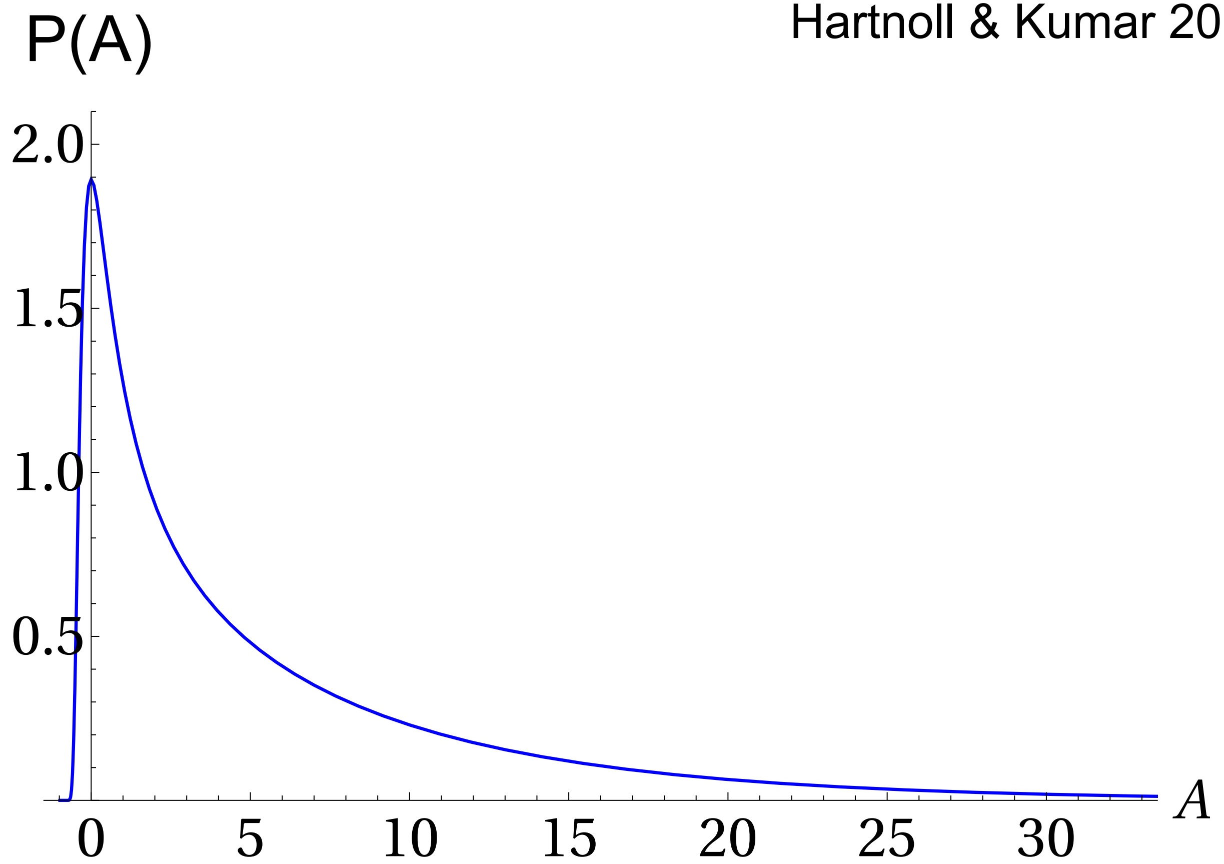
$$Z_{QFT}[^3\tilde{g}, \tilde{\phi}]$$

Toy model



Holographic Measure

[Bobev, TH, Vreys 2017;
Anninos, Denef, Harlow 2013;
Hartnoll & Kumar 2006]



Large fluctuations suppressed. No significant spreading.

A general argument

On constant density surfaces with $$R(h) < 0$$

one expects [Witten ('99)] $$Z(h) \to \infty$$

because $$Z_{QFT}[{}^3\tilde{g}, \tilde{\phi}] = \langle \exp \int d^3x \sqrt{\tilde{g}} \tilde{\phi} \mathcal{O} \rangle$$

where the action includes a conformal coupling term $R\varphi^2$.

A general argument

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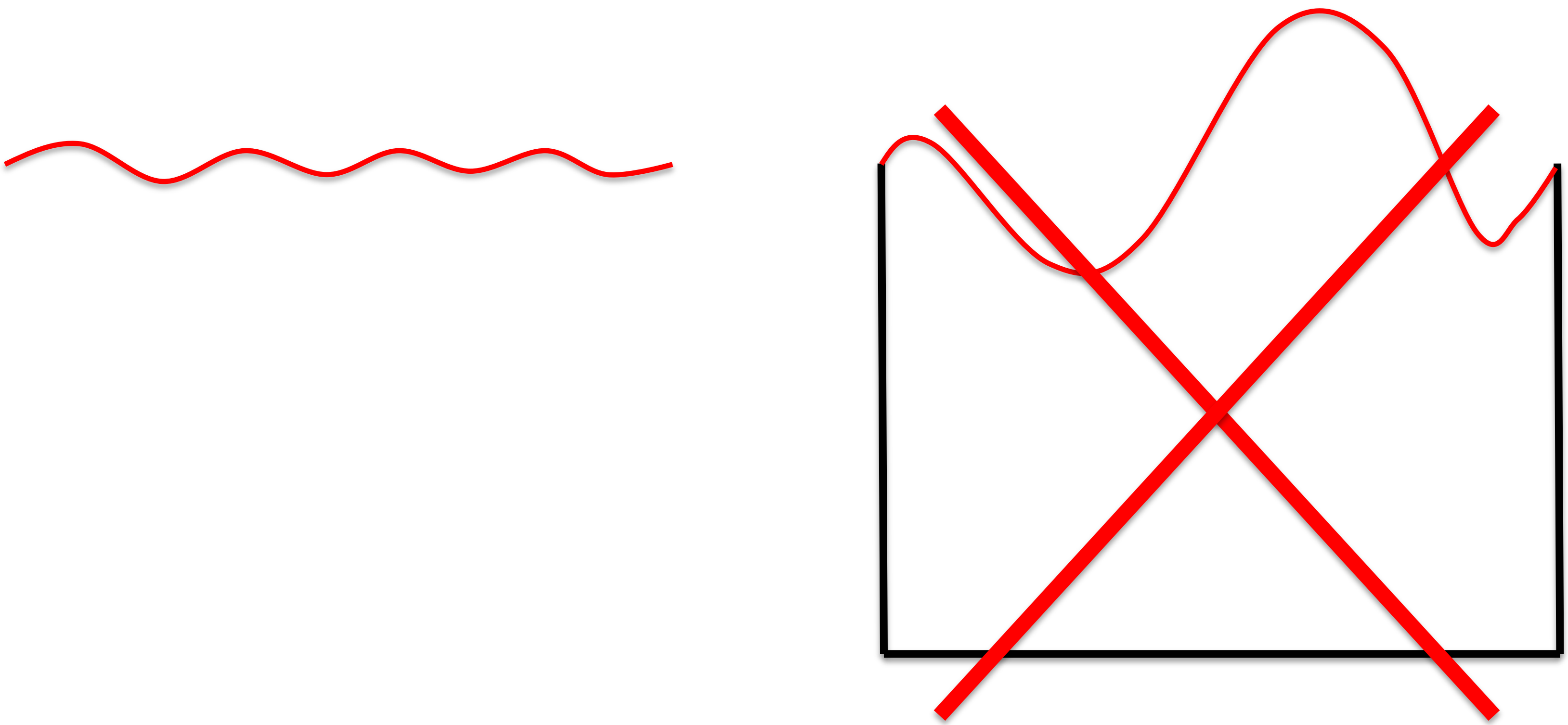
where the action includes a conformal coupling term $R\varphi^2$.

Since

$$|\Psi_{HH}(h,\chi)| = Z^{-1}_{QFT}(\tilde{h},\tilde{\chi})$$

this means the holographic measure strongly suppresses large deformations.

A smooth exit



Holography indicates the exit from eternal inflation gives a reasonably smooth big bang

[Hawking & TH ('18)]

Conclusion:

- The exit from eternal inflation is the birth of a classical universe.
- A reliable theory of eternal inflation must be based on quantum cosmology and should provide a prior sharpening the predictions of slow roll inflation
- The usual account of eternal inflation gives rise to a fractal-like `multiverse' on the largest scales
- We have put forward a novel, holographic description of eternal inflation which appears to predict a smooth big bang
- *Implications of holographic cosmology on observable scales?*