The question of the origin hides
the origin of the question.

François Jacqmin

Primeval Atom 2.0

Thomas Hertog

The Beginning of the World from the Point of View of Quantum Theory.

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G. LEMAÎTRE.
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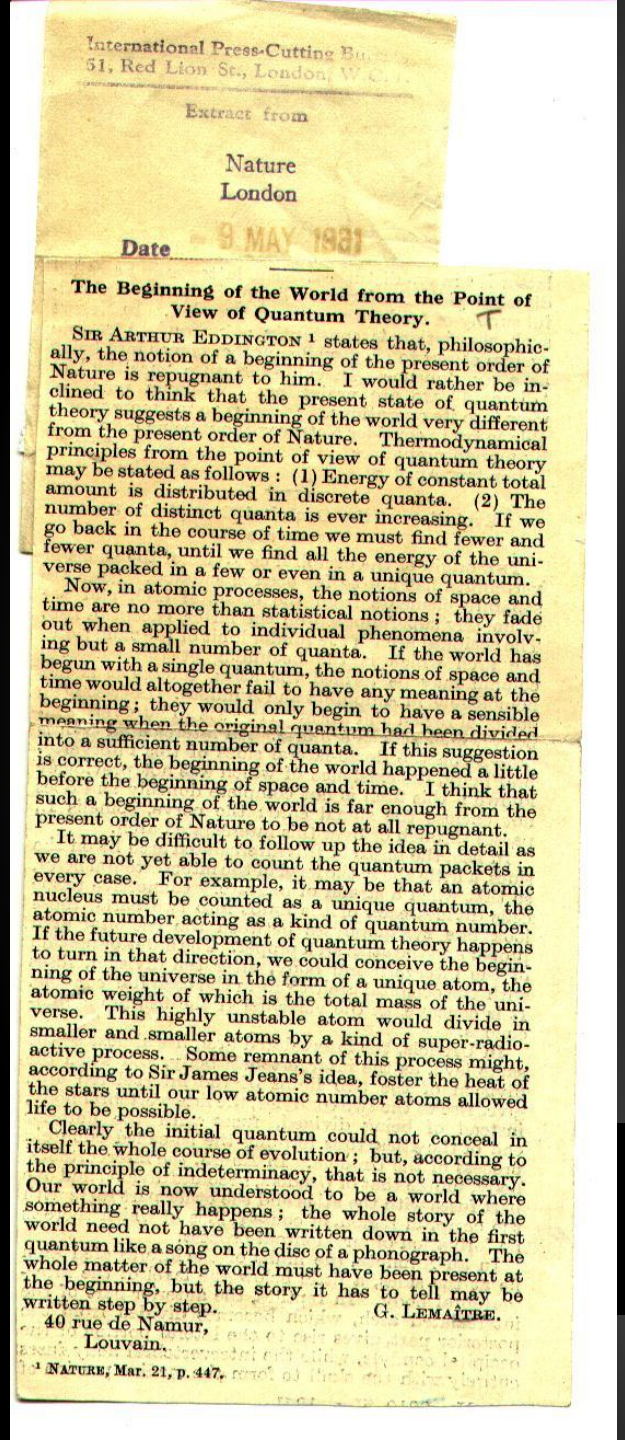
[1] NATURE, Mar. 21, p. 447.



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Holy Ghost College, Leuven, EPS historical site

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The End of the World: from the Standpoint of Mathematical Physics.*

By Sir ARTHUR S. EDDINGTON, F.R.S.

THE world—or space-time—is a four-dimensional continuum, and consequently offers a choice of a great many directions in which we might start off to look for an end; and it is by no

ahead of us is lengthening. It is like trying to run a race in which the finishing-tape is moving ahead faster than the runners. We can picture the stars and galaxies as embedded in the surface of a rubber

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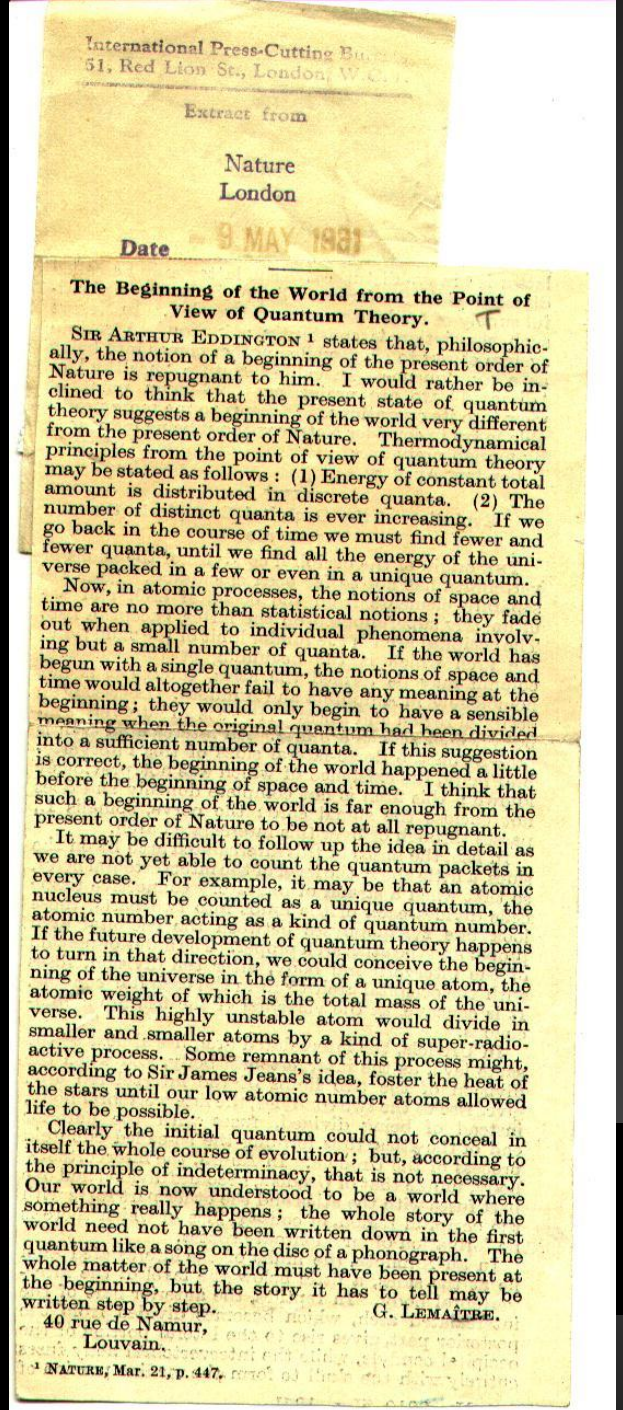

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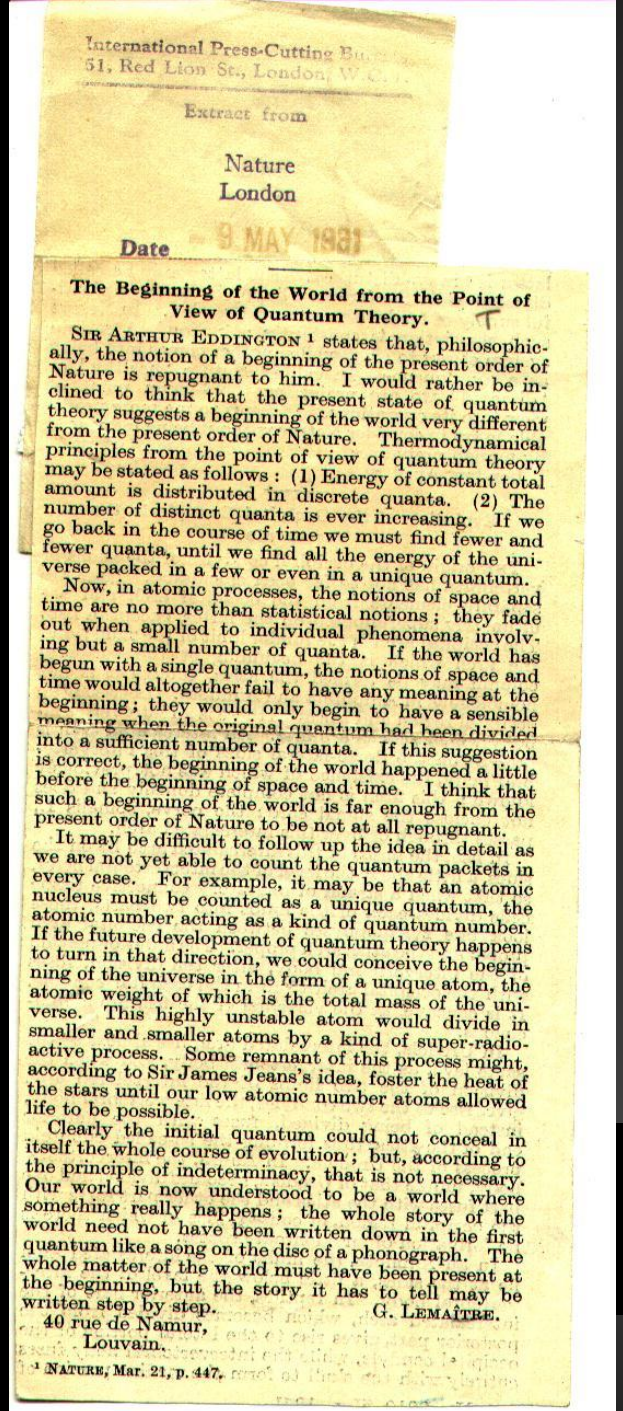

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I think that every one who believes in a supreme being supporting avery being and every acting, believes also that God is essentially hidden and may be glad to see how present physics provides a veil hiding the creation.


Wie gaat nadenken
over het probleem--

Around 1930 the Abbé Lemaitre visited Cambridge and gave a lecture at the Kapitza Club. There was much discussion about the indeterminacy of quantum mechanics. Lemaitre emphasized his opinion that he did not believe God influenced directly the course of atomic events.

A member of the audience made this drawing to commemorate this discussion. I do not remember who the artist was. It is quite a good likeness of Lemaitre.

P A M Dirac 1st Sept 1971

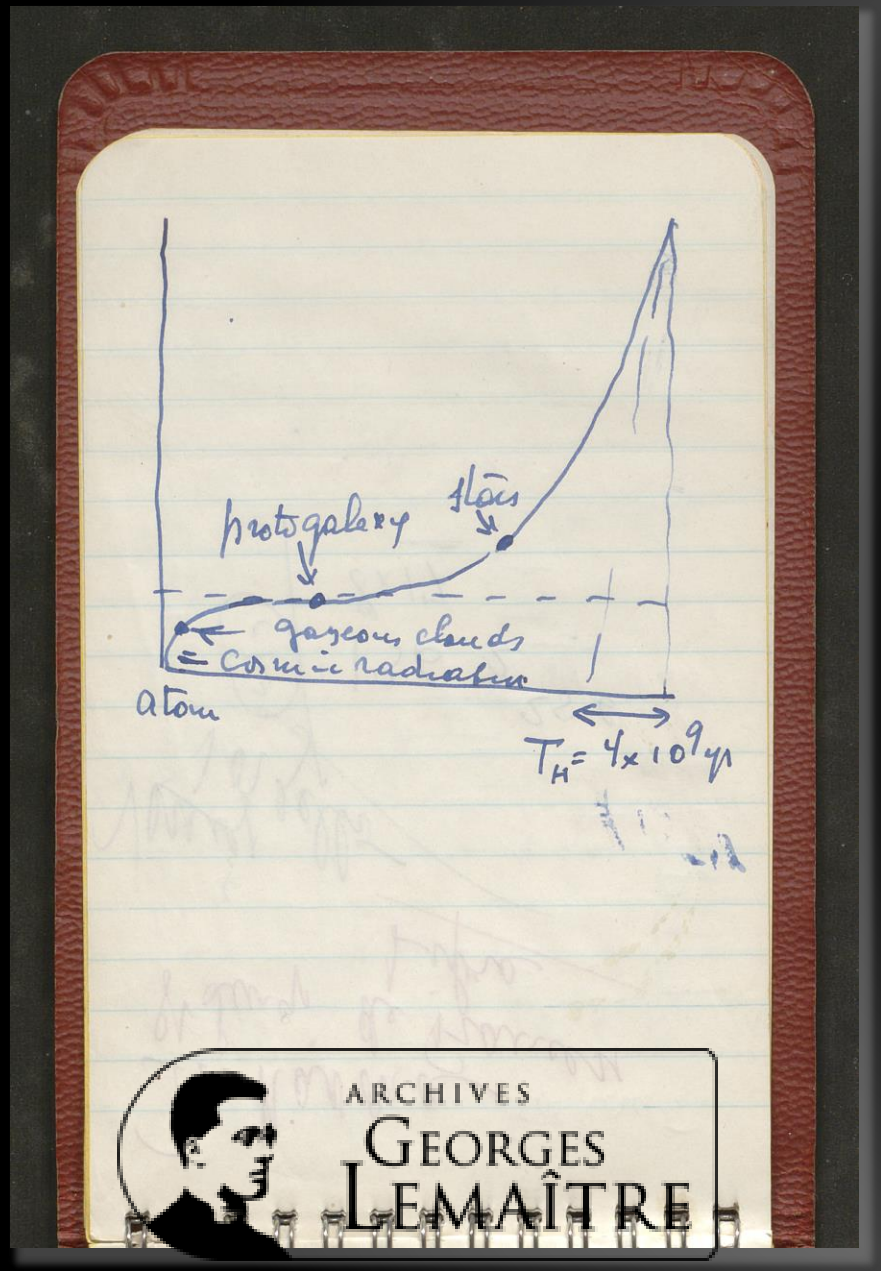
The new cosmology may turn out to be philosophically even more revolutionary than relativity or the quantum theory…

I find the separation between laws and initial conditions unsatisfactory philosophically, as it goes against all ideas of the unity of Nature...”

What, then, becomes of the initial conditions [in cosmology]?
Plainly there cannot be any, or they must be trivial.

Quantum mechanics enables us to ascribe the complexity of the universe not to the complexity of initial conditions but to quantum jumps along the way…

Paul Dirac, Scott lecture, 1939



- An expanding universe
- with a cosmological constant
- emerging from the disintegration of a ‘primeval atom’,
- representing a natural quantum origin, part of science yet inaccessible in its simplicity,
- that comes with relic radiation.

“Standing on a cooled cinder, we see the slow fadings of the suns, and we try to reconstruct the vanished brilliance of the origin of the worlds.”

Primeval Atom 2.0

Wave function of the Universe

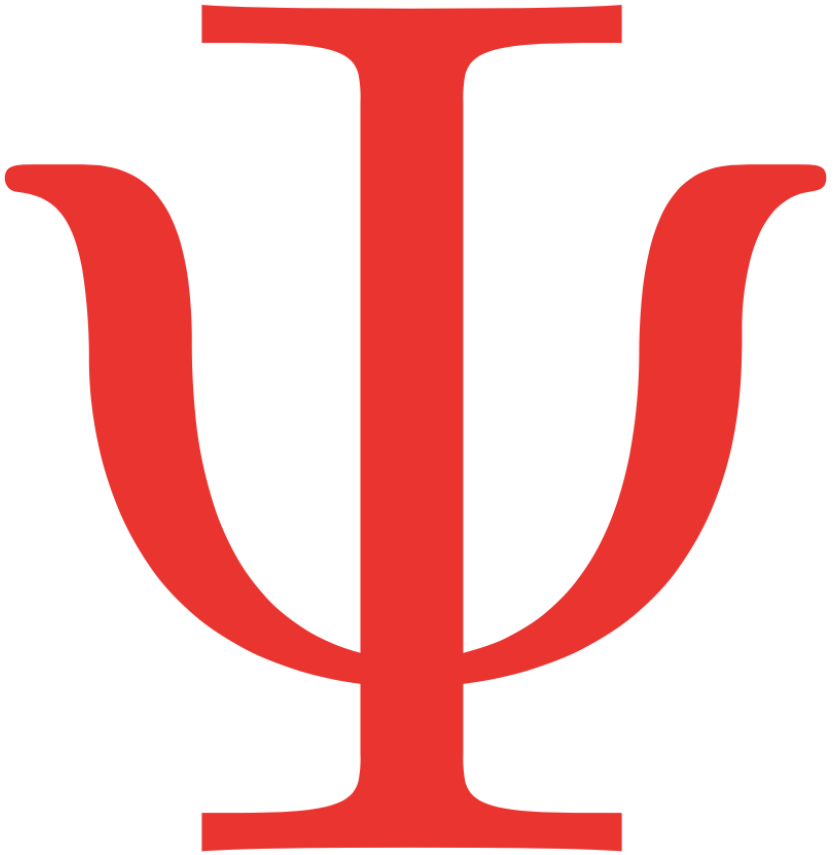
J. B. Hartle
Enrico Fermi Institute, University of Chicago, Chicago, Illinois 60637
and Institute for Theoretical Physics, University of California, Santa Barbara, California 93106

S. W. Hawking
Department of Applied Mathematics and Theoretical Physics, Silver Street, Cambridge, England
and Institute for Theoretical Physics, University of California, Santa Barbara, California 93106


Cet instant unique, qui n'avait pas
Georges Lemaître (1894 - 196
Père de la Théorie du Big Bang
Gigi Warny, 2016

A Quantum Universe

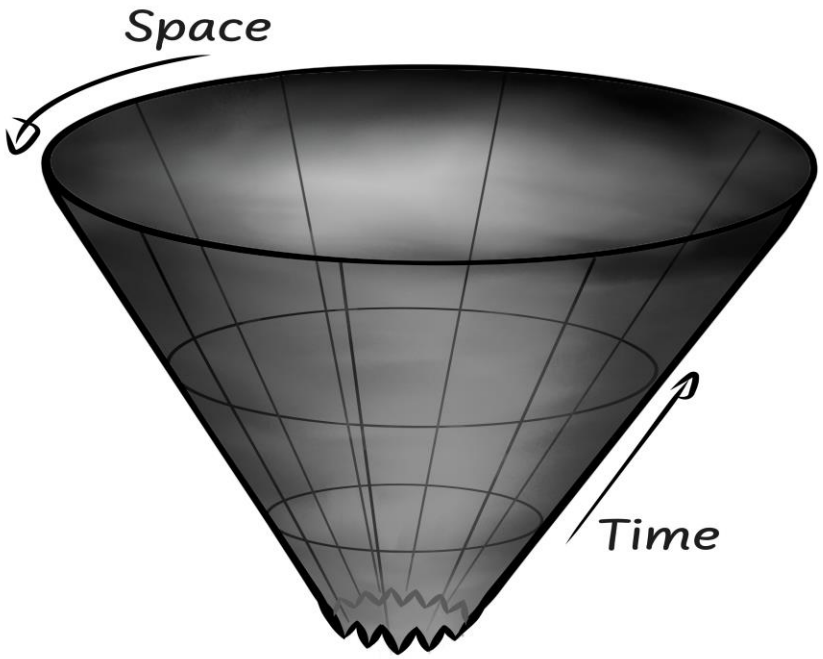
If the universe is a quantum mechanical system it has a quantum state.
What is it?



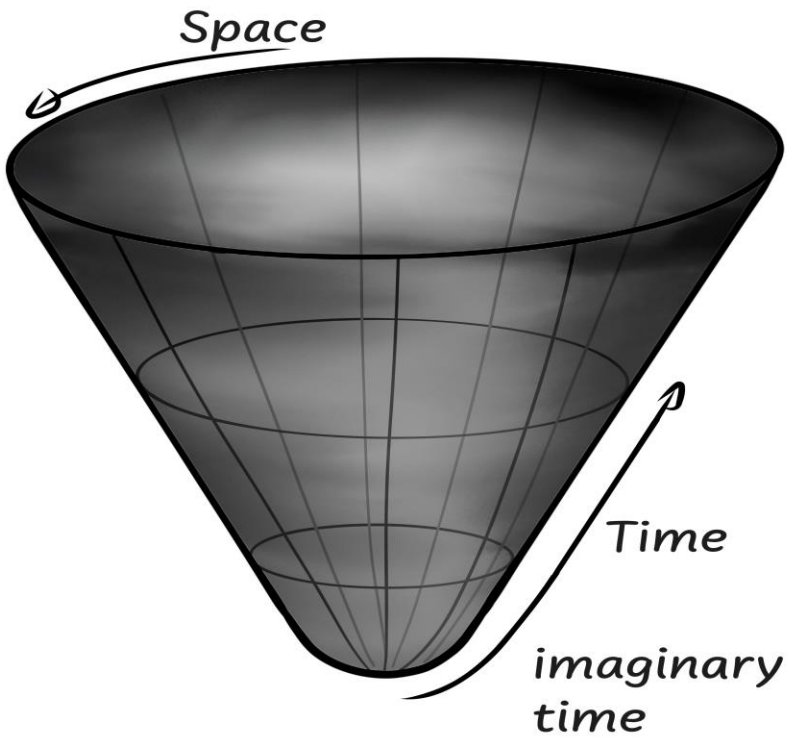
That is the problem of Quantum Cosmology.

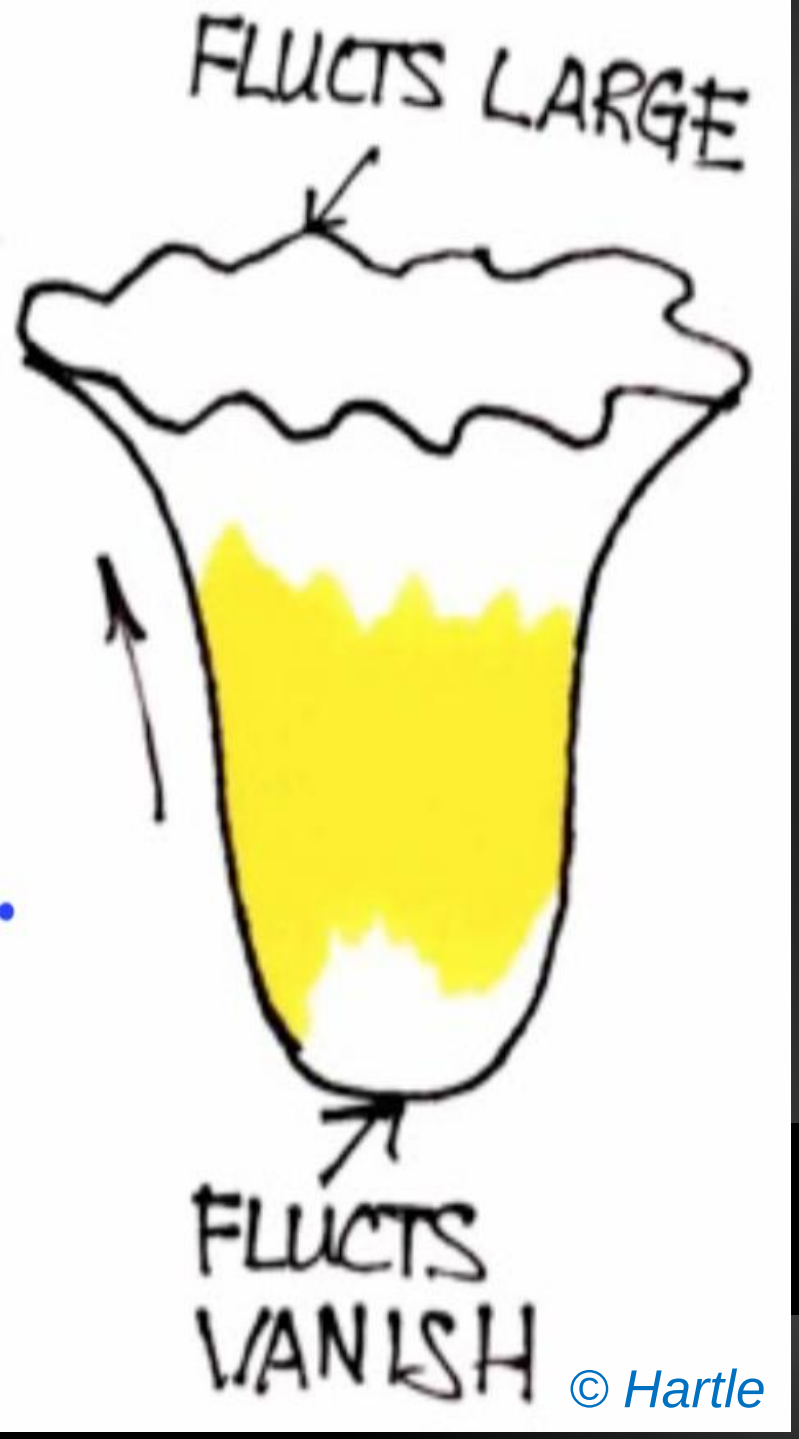
A theory of the
quantum state
of the universe
is as much a part of a
final theory
as a theory of dynamics.

CLASSICAL

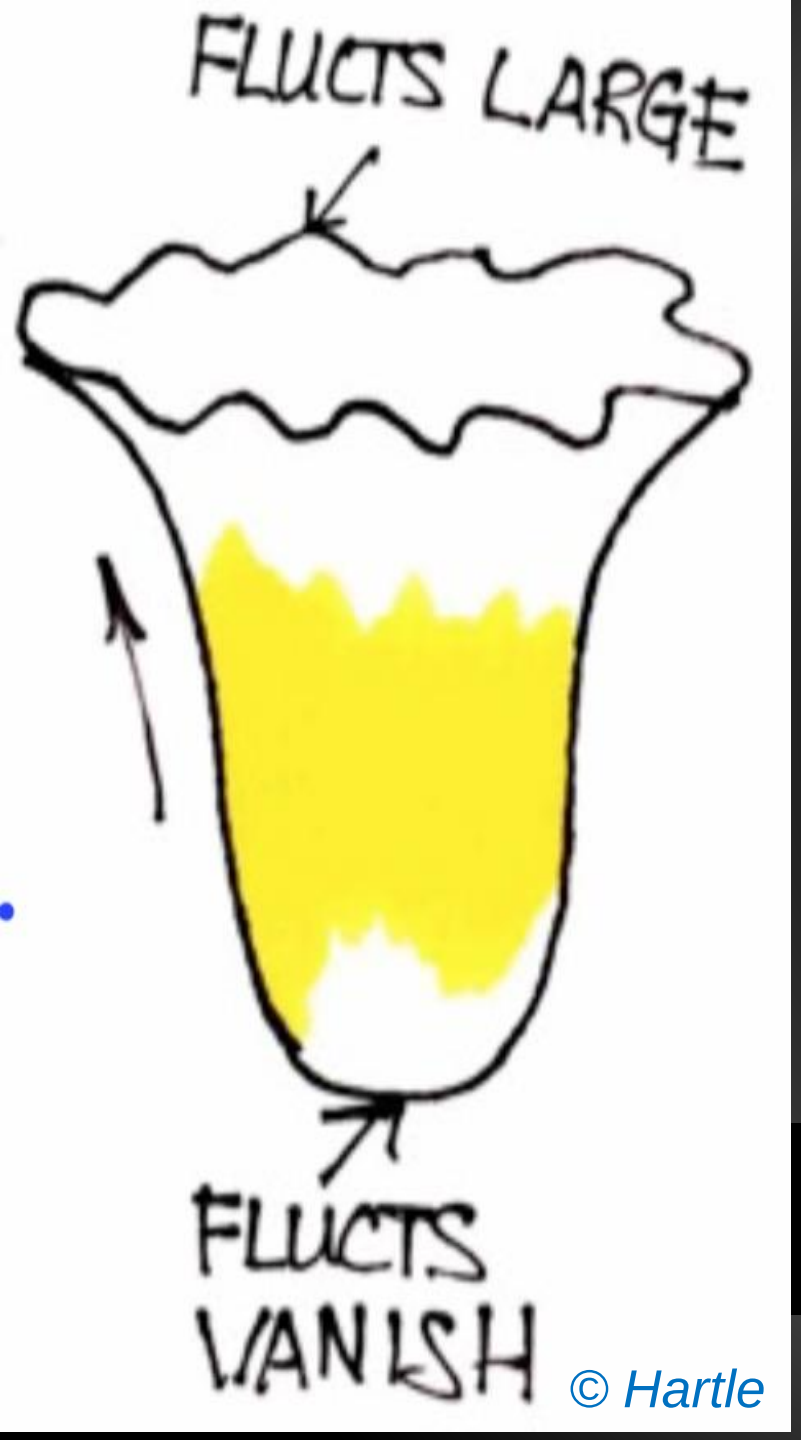


QUANTUM





- An expanding universe
- with an early phase of inflation,
- emerging from a quantum origin,
- with fluctuations initially in their ground state
- leading to an arrow of time.



- An expanding universe
- with an early phase of inflation,
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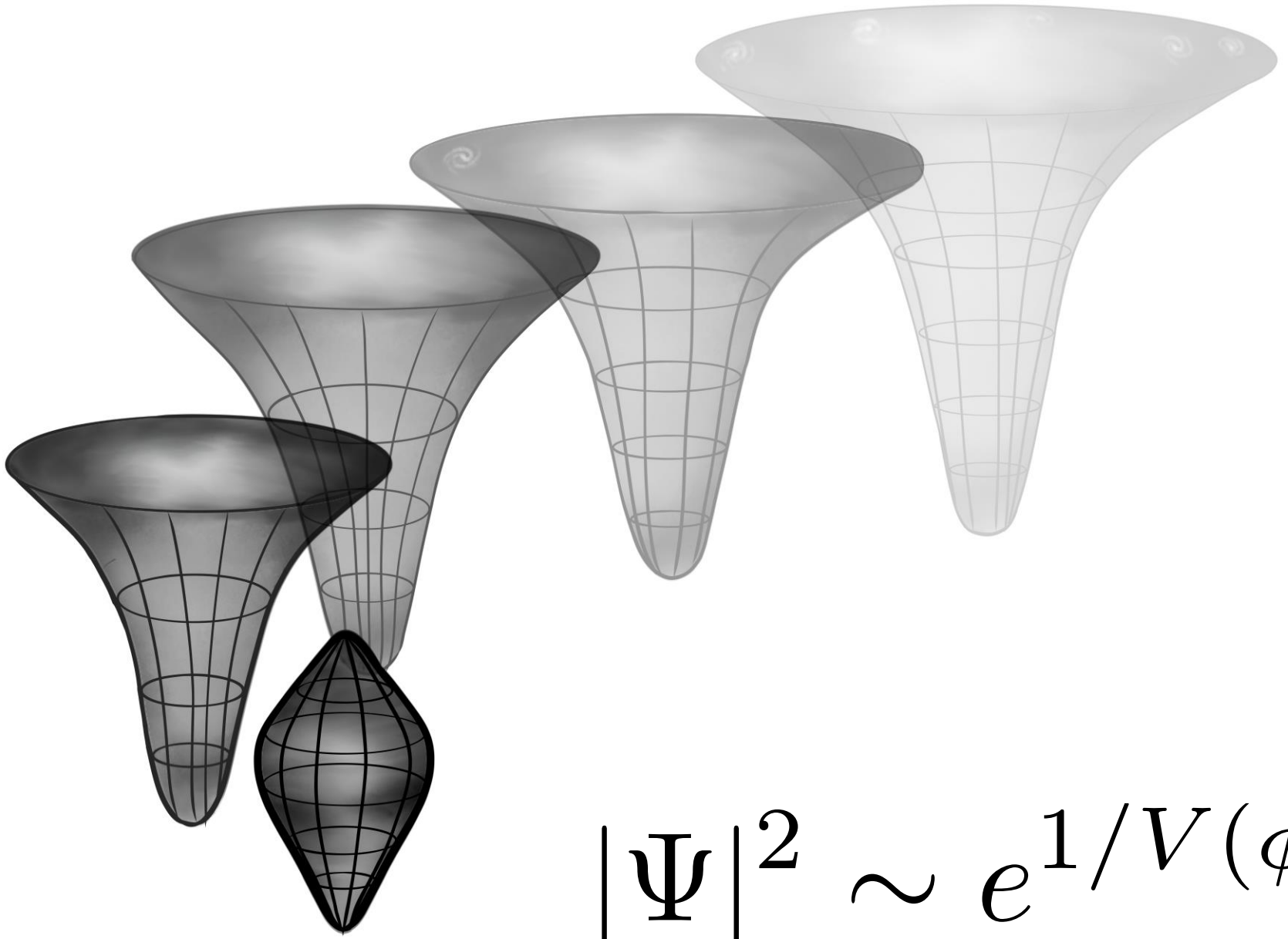
“By the path integral over compact metrics, one eliminates one of the two parts of physics, the boundary conditions.

There ought to be something very special about the boundary conditions of the universe and what can be more special than that there no boundary.”

S.W. Hawking, Proc. Pontifical Academy, 1981



$$|\Psi|^2 \sim e^{1/V(\phi_i|)}$$

What if we let go of the Archimedean standpoint ``from outside''?

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What if we turn cosmology inside out?

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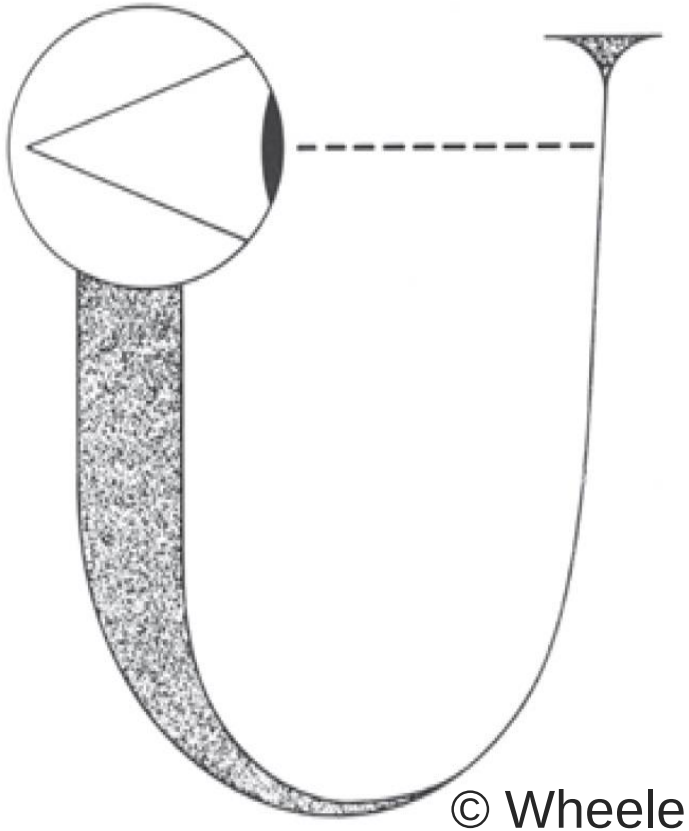

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PRL **100,** 201301 (2008) PHYSICAL REVIEW LETTERS week ending 23 MAY 2008

No-Boundary Measure of the Universe 2.0

James B. Hartle,[1] S. W. Hawking,[2] and Thomas Hertog[3]

[1]*Department of Physics, University of California, Santa Barbara, 93106, USA*

[2]*DAMTP, CMS, Wilberforce Road, CB3 0WA Cambridge, United Kingdom*

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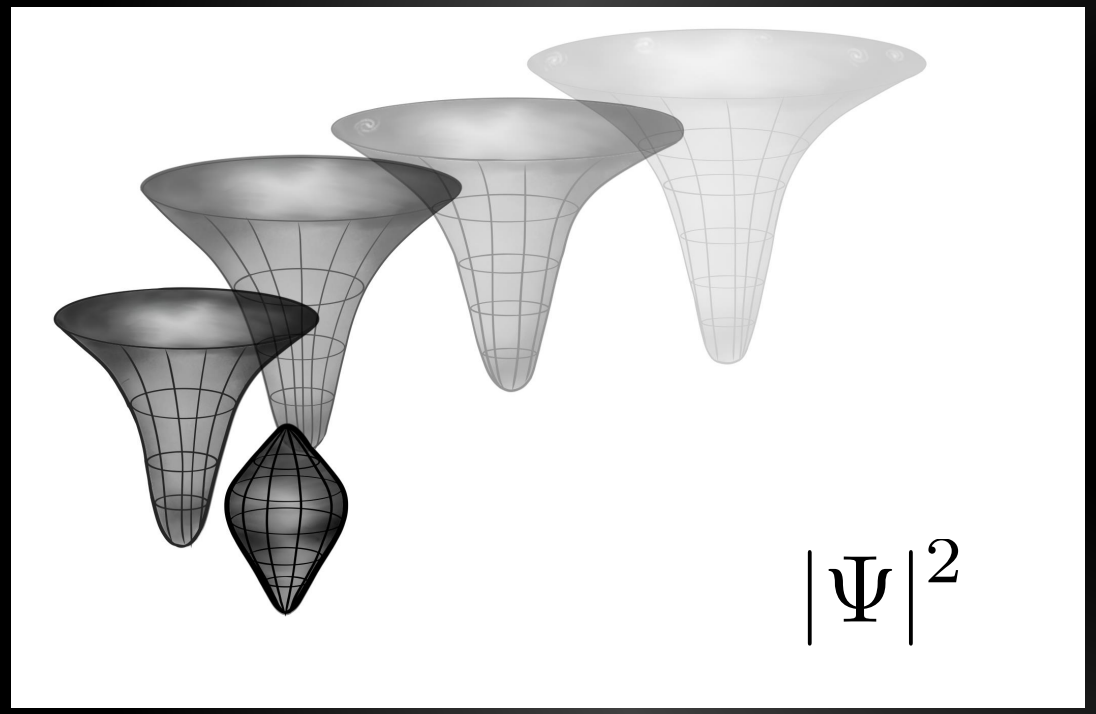
(Received 8 February 2008; published 23 May 2008)

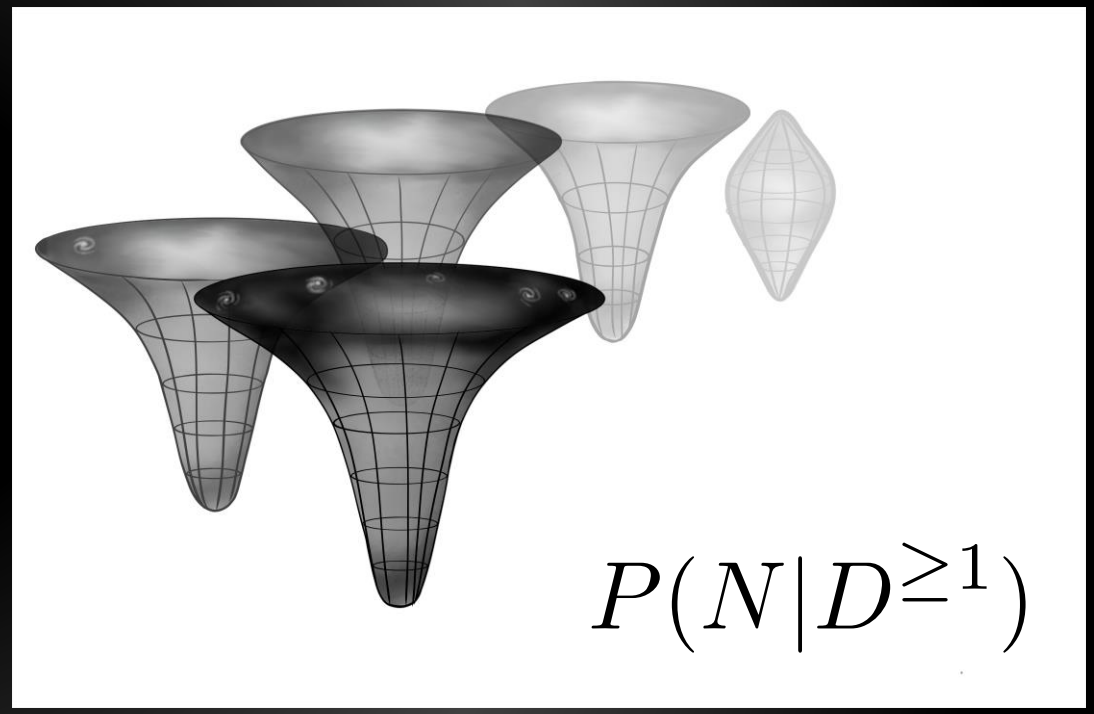
We consider the no-boundary proposal for homogeneous isotropic closed universes with a cosmological constant and a scalar field with a quadratic potential. In the semiclassical limit, it predicts classical behavior at late times if the scalar field is large enough. The classical histories may be singular in the past or bounce at a finite radius. This probability measure selects inflationary histories but is biased towards small numbers of e-foldings N. However, to obtain the probability of our observations in our past light cone these probabilities should be multiplied by $\exp(3N)$. This volume weighting is similar to that in eternal inflation. In a landscape potential, it would predict that the Universe underwent a large amount of inflation and could have always been semiclassical.

$$P(N|D^{\geq 1})$$

No-boundary measure



No-boundary measure 2.0



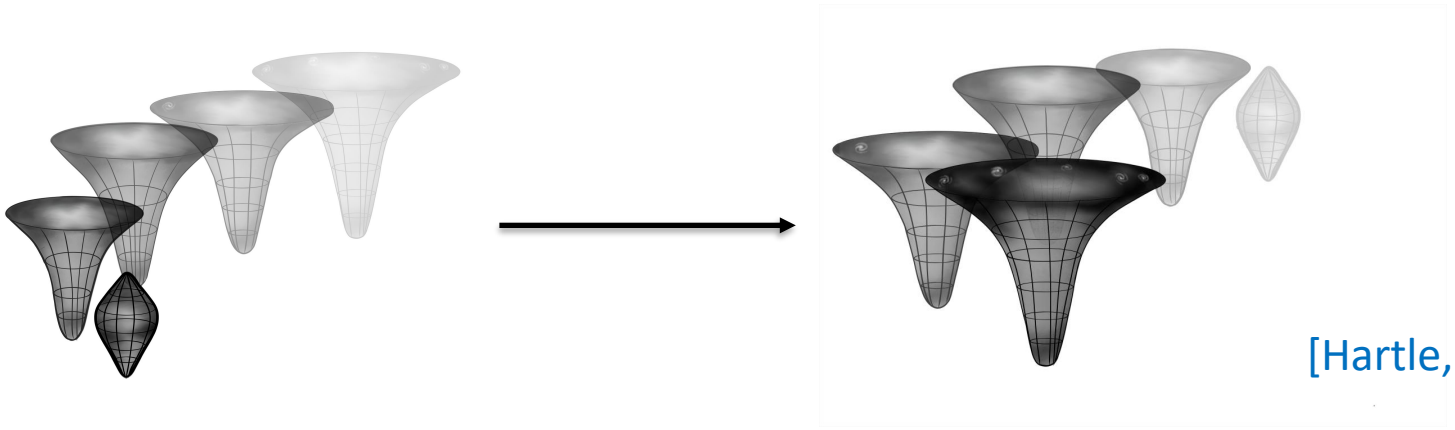
no-boundary measure 2.0

$|\Psi|^2$

$$P(N|D^{\geq 1}) \sim \left(1 - [1 - p_H(D)]^{N_H(N)}\right) \exp[3\pi/m^2 N]$$

This distribution exhibits a Page-like transition:

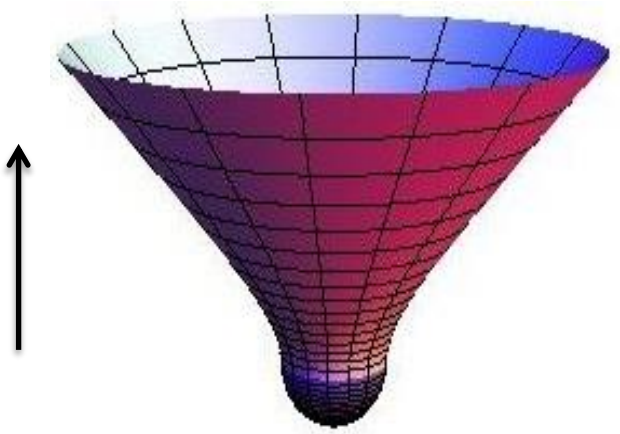
- No data or few data D → low N saddle dominates
- Lots of data D → large N saddle dominates



[Hartle, Hawking, Hertog, 2011]

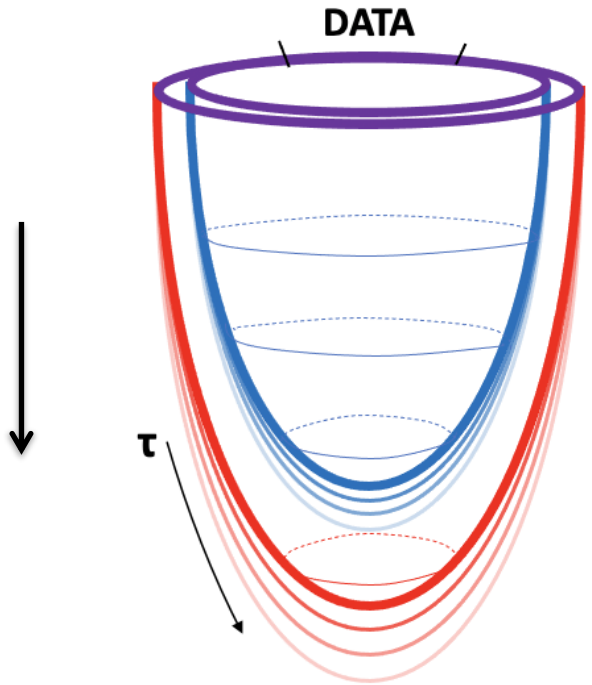
no-boundary measure 2.0

1983



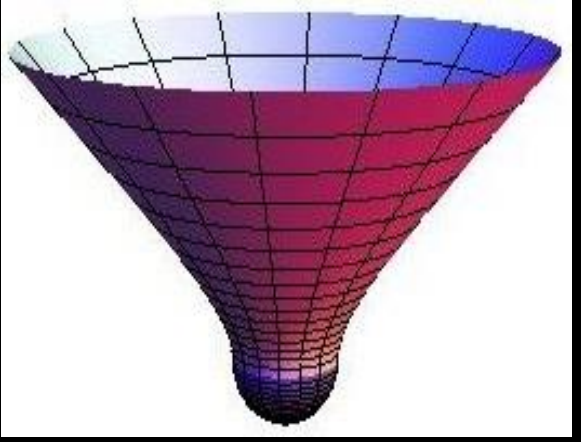
‘creation from nothing’

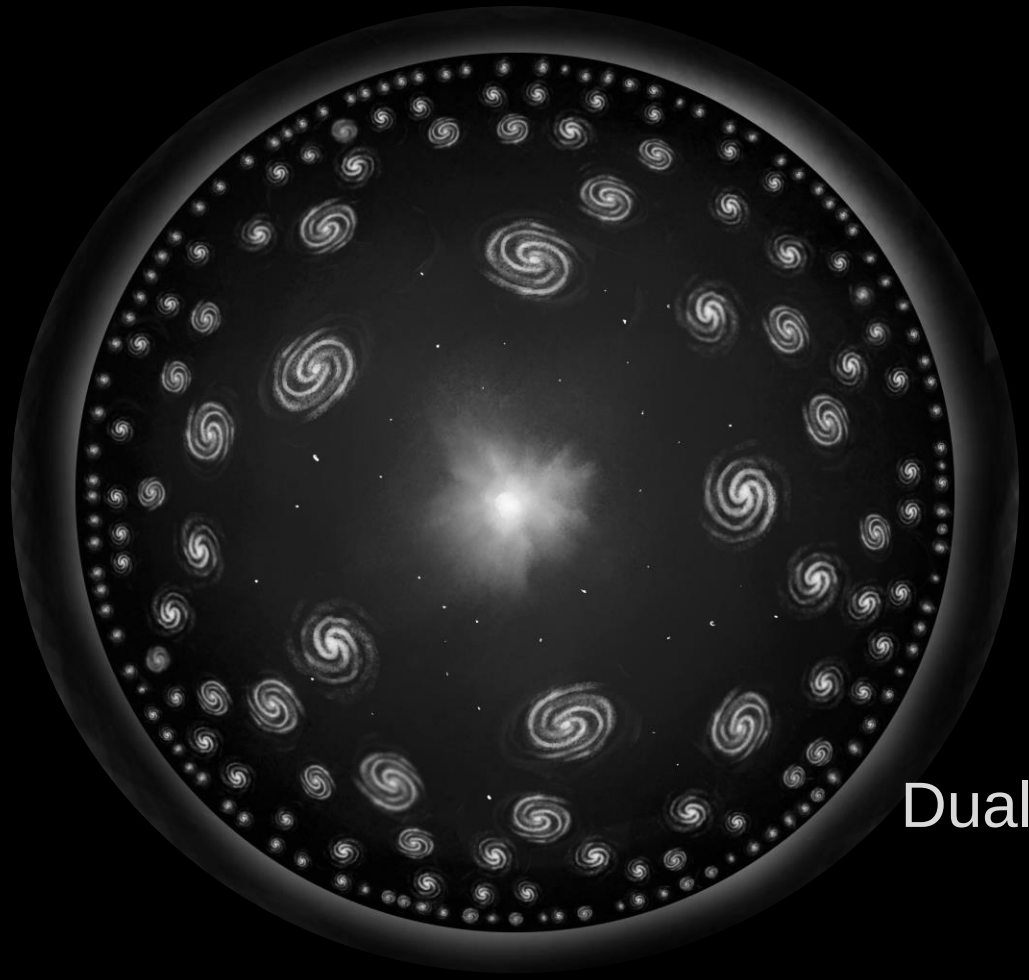
2011



top- down view

HOLOGRAPHIC COSMOLOGY





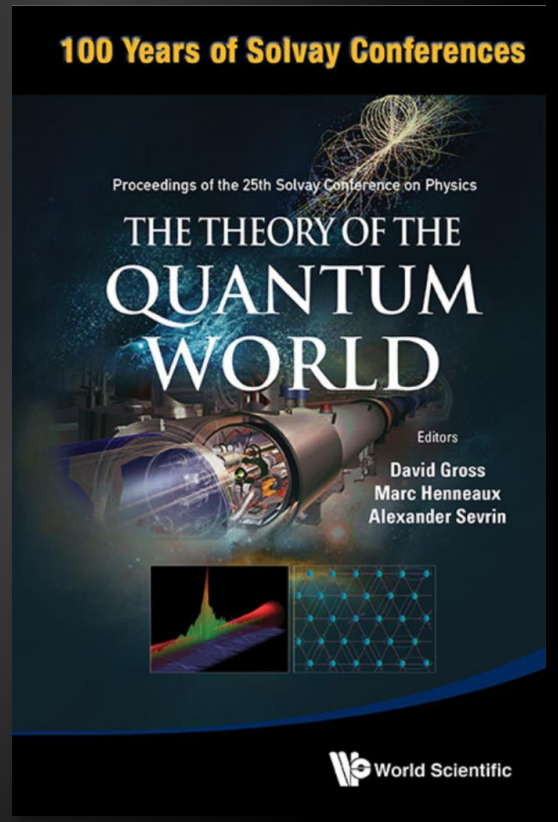
Dual QFT

In holography [in AdS], what defines the theory are the boundary conditions.

So maybe in our world what defines the theory is the question we are asking.

Bad questions give zero.. all good questions have some answer..

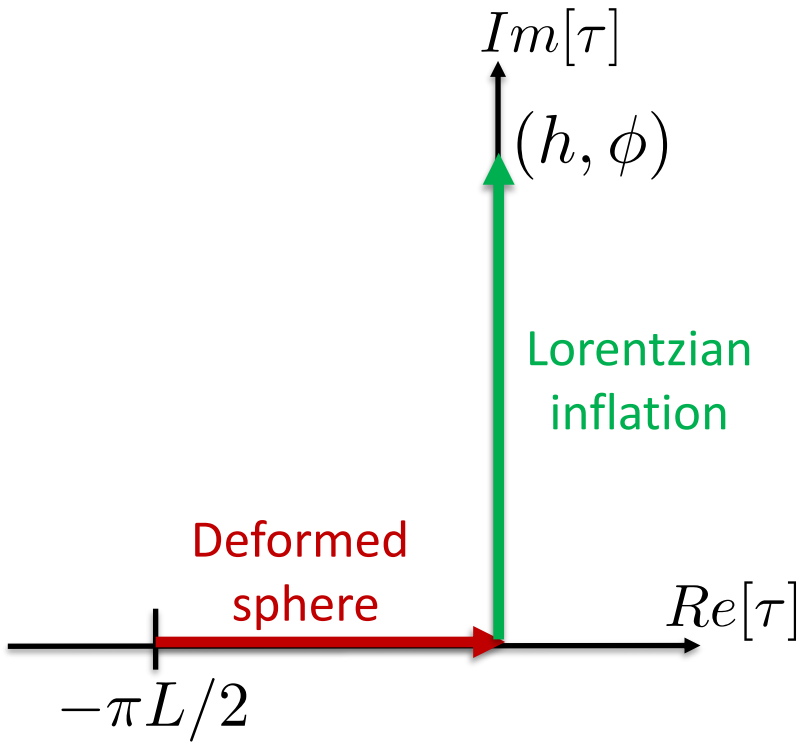
J. Maldacena, Proceedings 25th Conseil Solvay, 2011

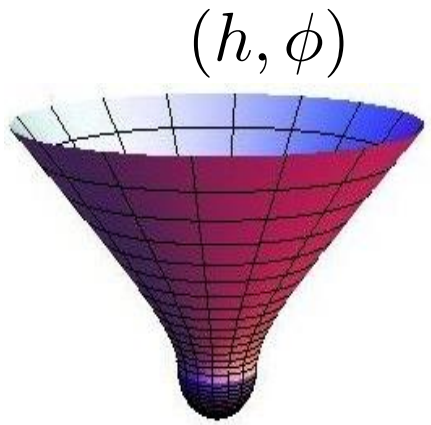


Holographic no-boundary measure

[Hartle,TH; Maldacena;Harlow, Stanford; Anninos et al.;…]

$$\Psi_{HH} = \mathcal{A}_{sp} e^{iS}$$





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[Hartle,TH; Maldacena;Harlow, Stanford; Anninos et al.;…]

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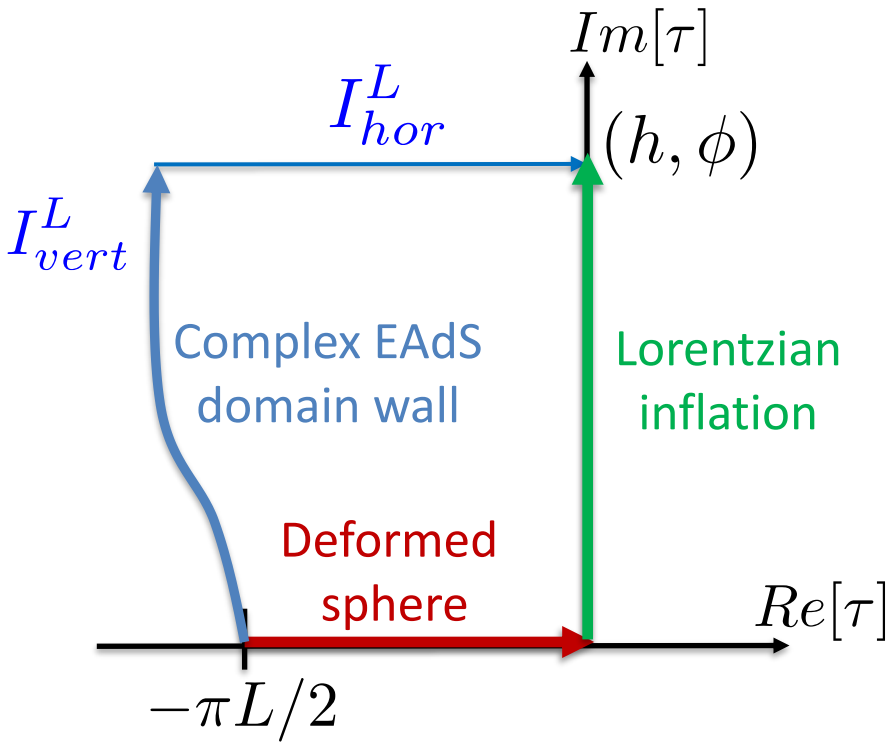
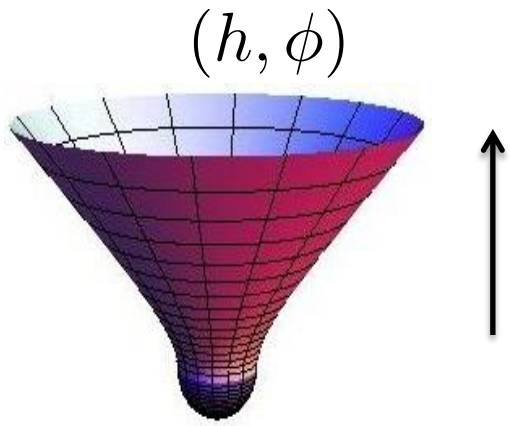


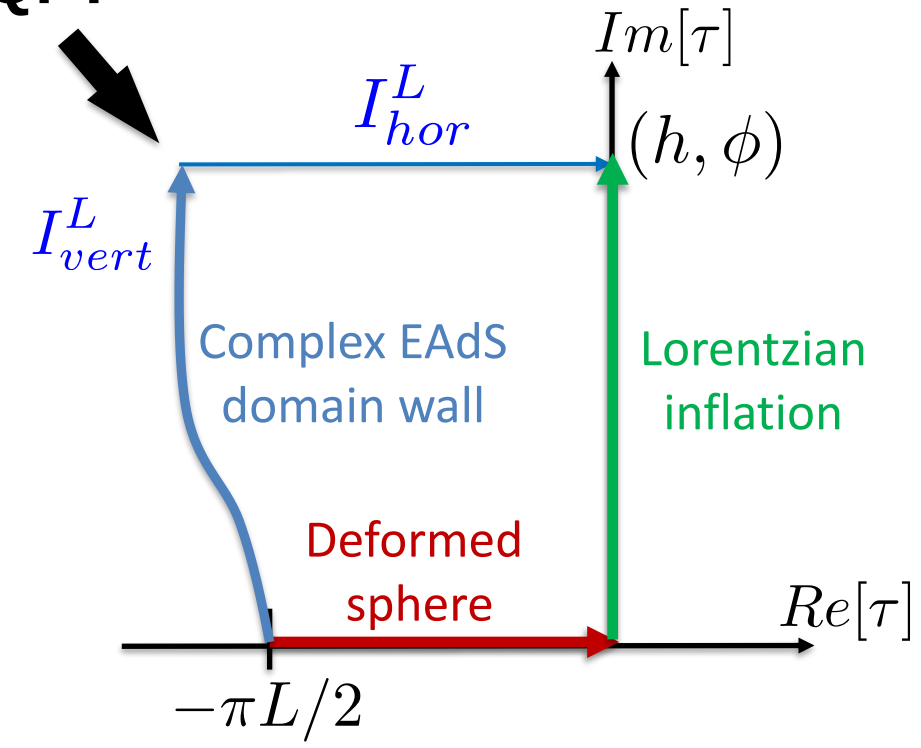


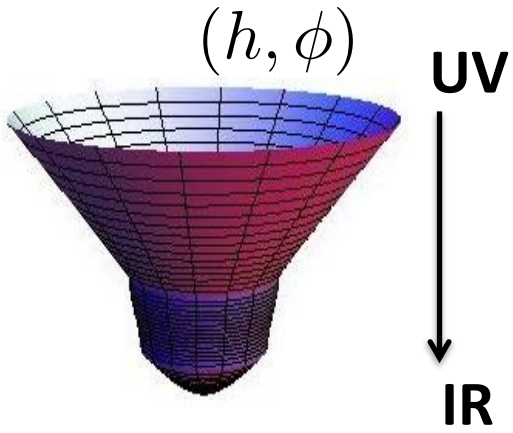
Holographic no-boundary measure

[also: Maldacena;Harlow, Stanford]

$$\Psi_{HH} = \mathcal{A}_{sp} e^{iS} \qquad \log \mathcal{A}_{sp} = I^{\rm reg}_{as{\rm EAdS}}$$

Dual QFT



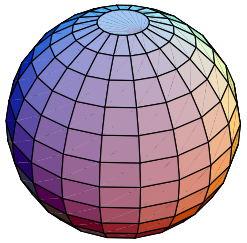


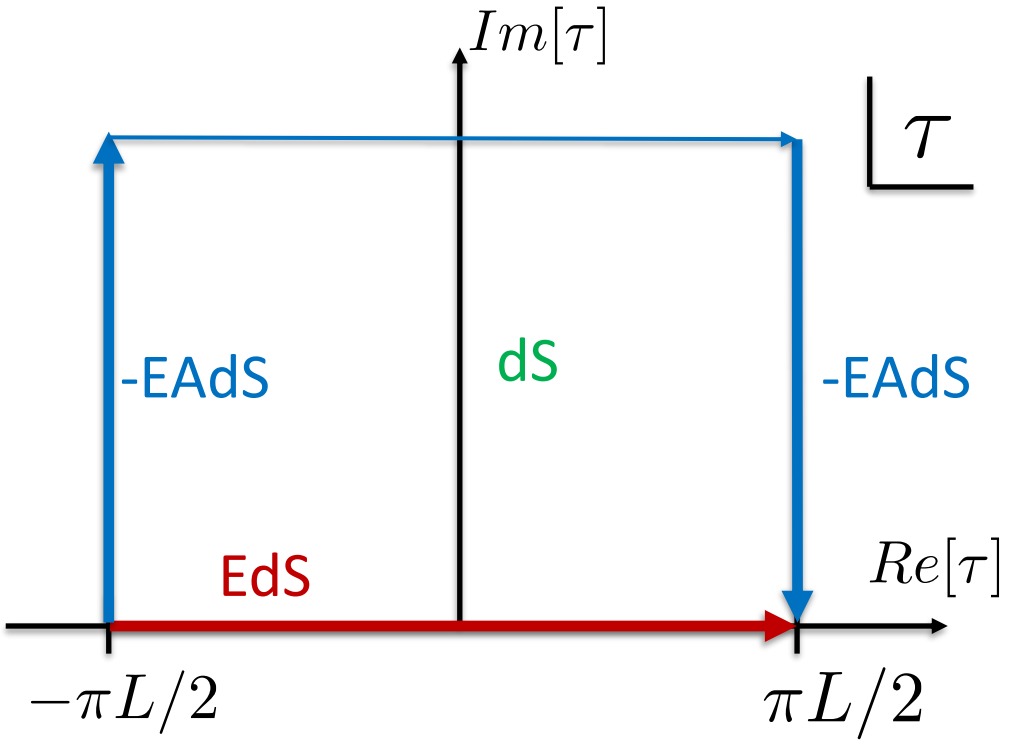
de Sitter entropy

[Bobev, TH, Hong, Karlsson, Reys]

$$\Psi^* \Psi \sim e^{-I_{EdS}}$$

$$I_{EdS} = -2\, I^{\rm reg}_{\rm EAdS}$$





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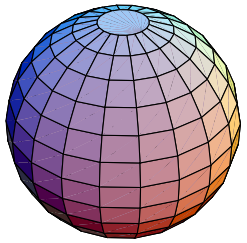
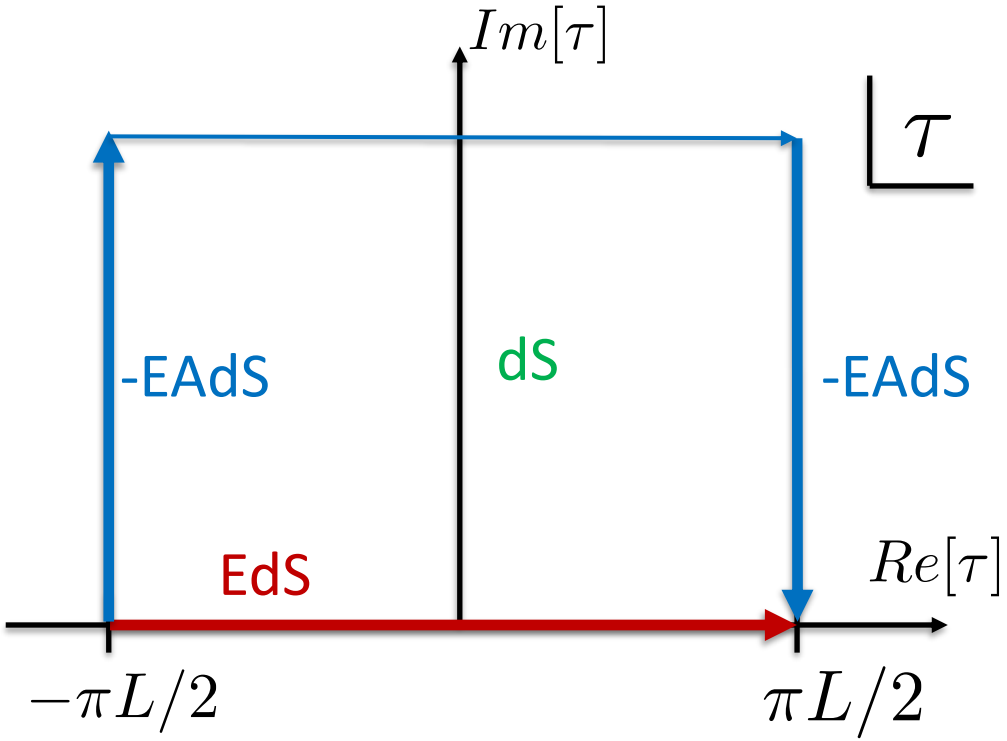
Conjecture: $\boxed{S_{dS} = -2 \log Z^{\rm CFT}_{S^3}}$



$$\boxed{Z_{S^4} \longleftrightarrow Z^{QFT}_{S^3}\, Z^{QFT}_{S^3}}$$



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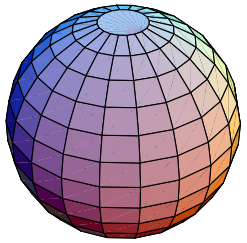
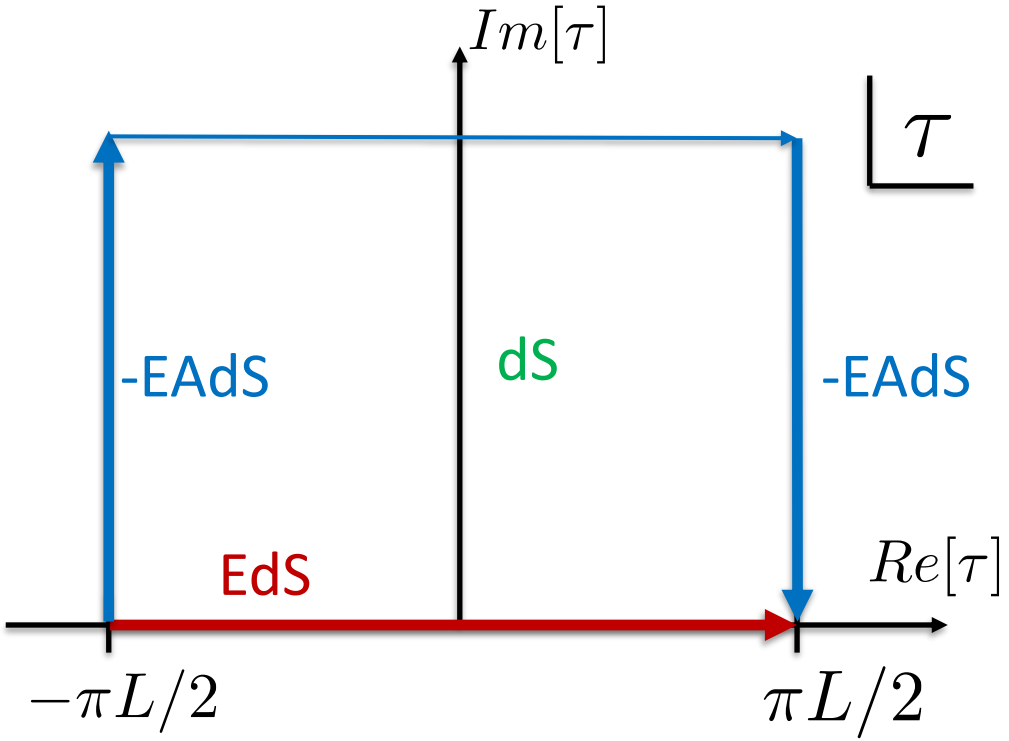




de Sitter entropy: microscopics

$$EAdS_4 \times S^7/\mathbb{Z}_k$$

$$S_{dS} = -I_{EdS} = 2I^{\rm reg}_{\rm EAdS} = -2\log Z^{\rm ABJM}_{S^3}$$

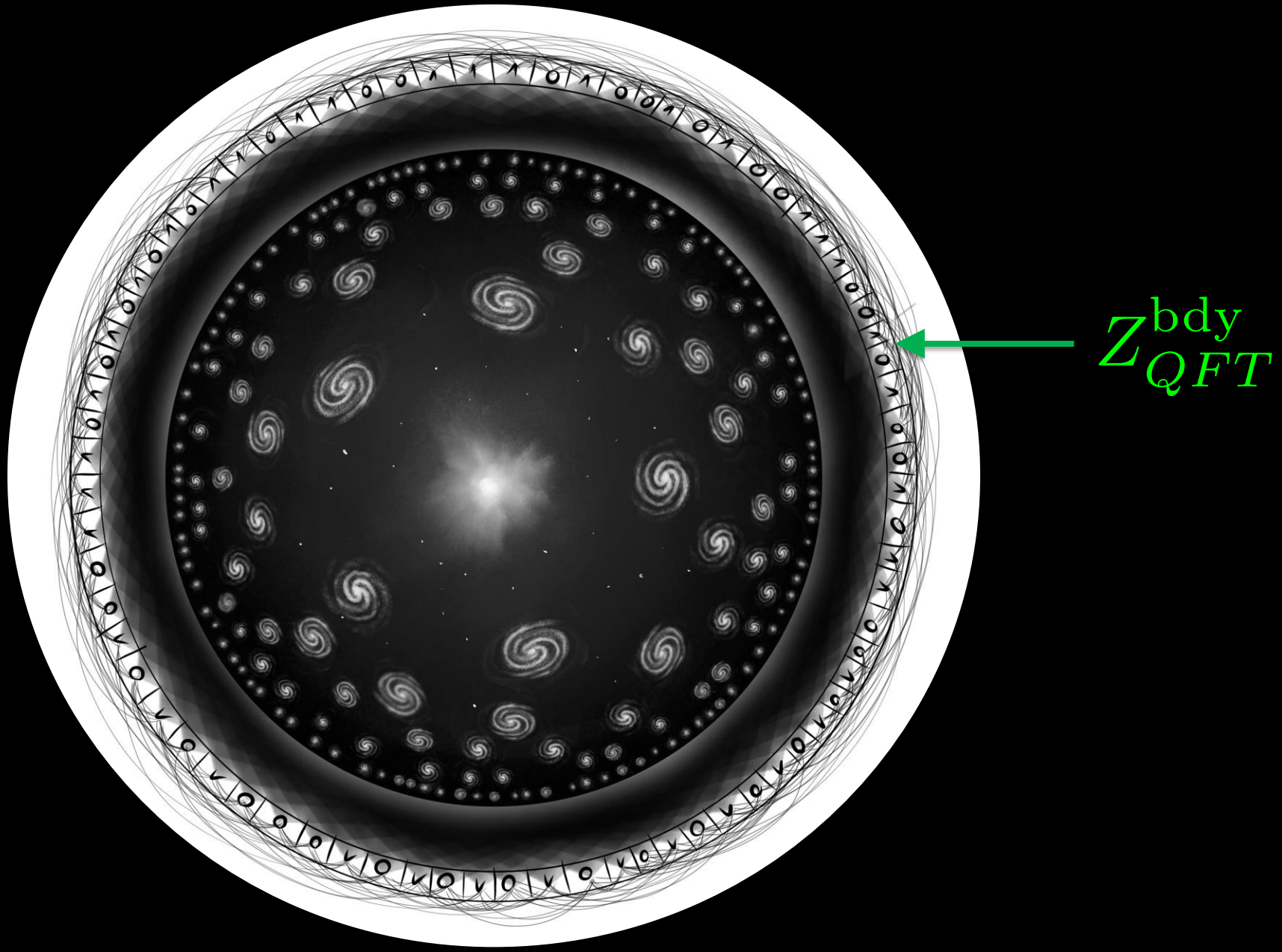
[Marino, Putrov; Fuji, Hirano, Moriyama; many others…]

$$\mathcal{S}_{\rm dS} = \frac{2\pi\sqrt{2k}}{3}N^{3/2} - \frac{\pi(k^2+8)}{12\sqrt{2k}}N^{1/2} + \frac{1}{2}\log N + \mathcal{O}(N^0)$$

- Leading term: matches Gibbons-Hawking entropy
- Subleading term: higher-derivative terms in sugra

  [Bobev, Charles, Hristov, Reys ‘21]
- Log correction: matches one-loop determinant

  [Bhattacharyya, Grassi, Marino, Sen]

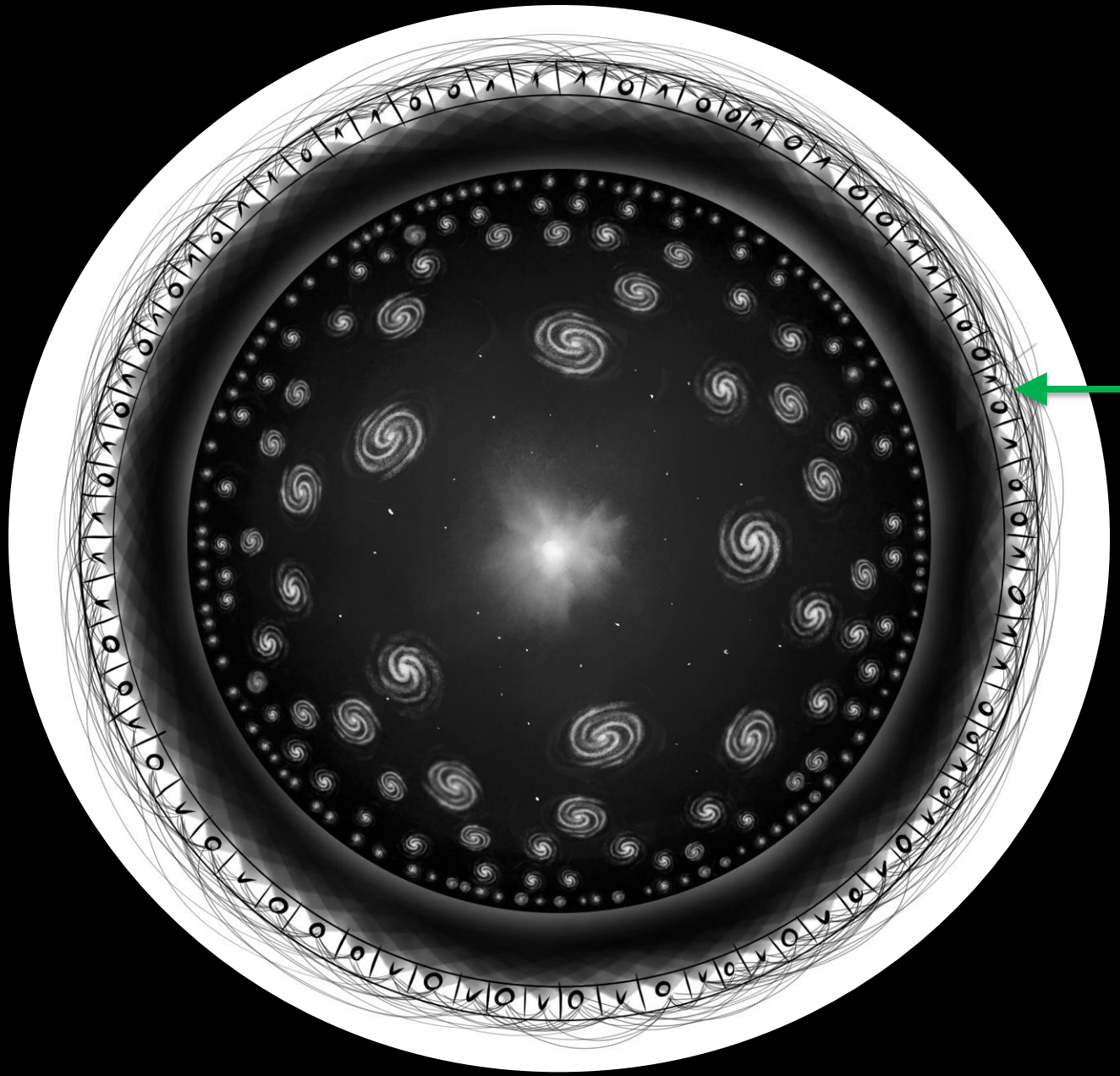

Z^{bdy}_{QFT}

RUNNING OUT OF d.o.f.

PAST HISTORY

GRAVITY in INTERIOR

DUAL QFT on OUTER BDY



Z^{bdy}_{QFT}

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ONZIÈME CONSEIL DE PHYSIQUE

tenu à l'Université de Bruxelles
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ET
L'ÉVOLUTION DE L'UNIVERS

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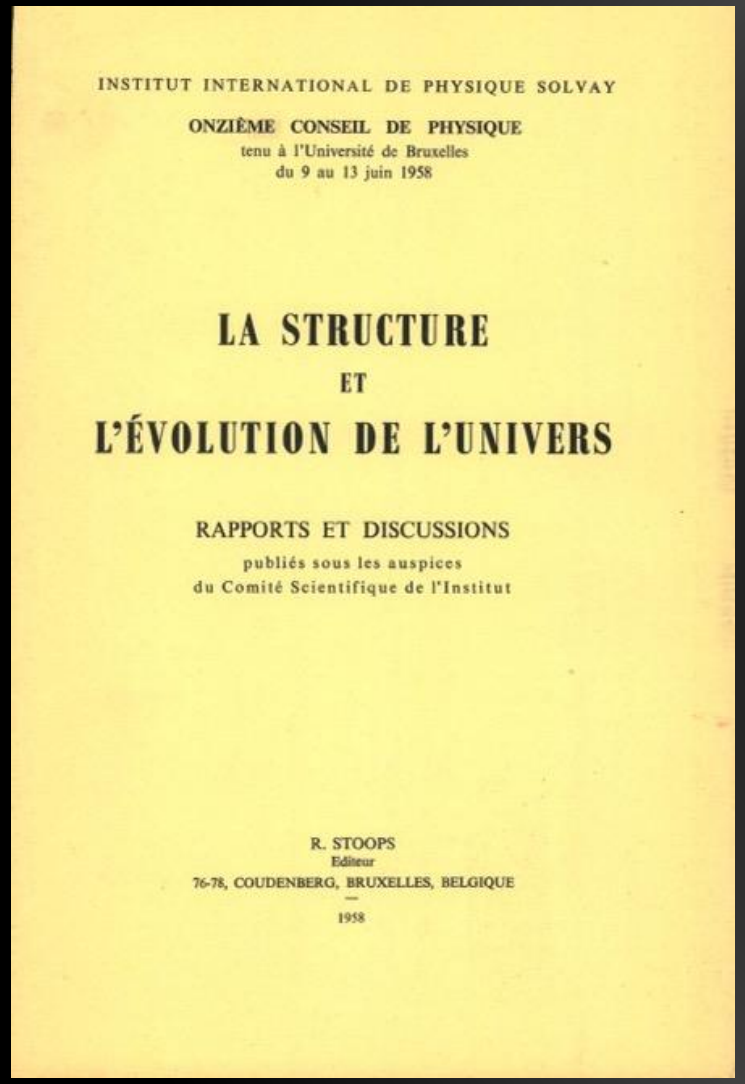
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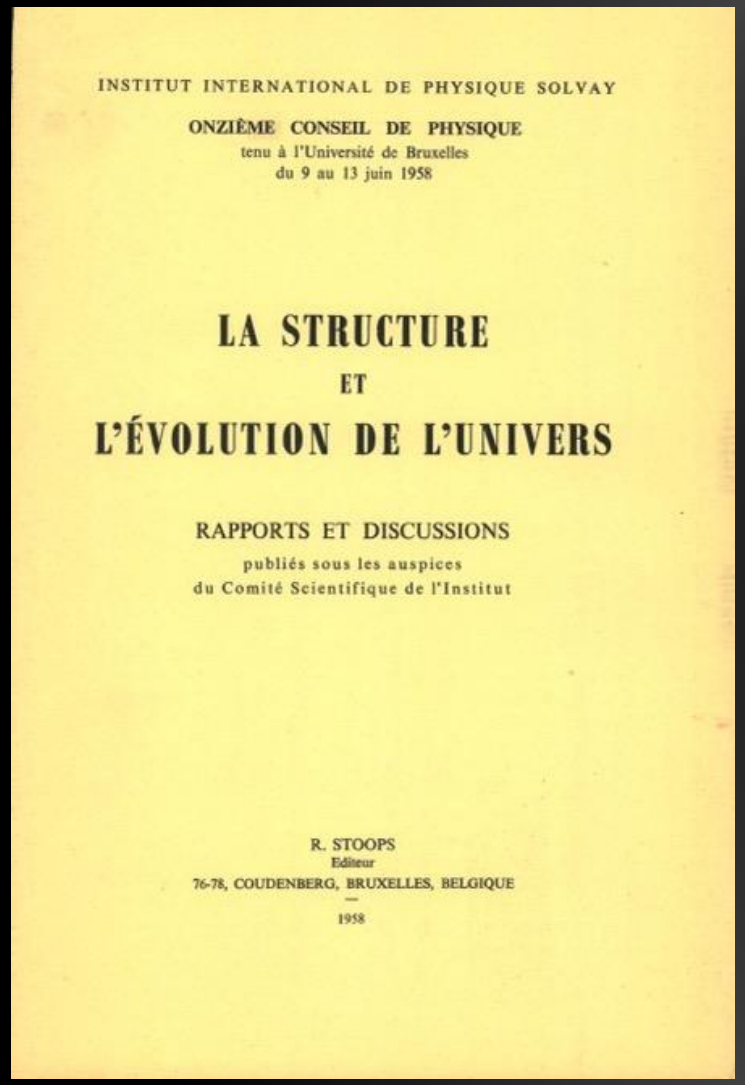
"the splitting of the Atom can have occurred in many different ways"—Everett's branching

"there would be little interest to know their relative probabilities"— no typicality

"Deductive cosmology cannot begin before the splitting has proceeded far enough" -- decohere

"Any information on the state of matter at this point must be inferred from the condition that the actual universe has been able to evolve from it"— top- down view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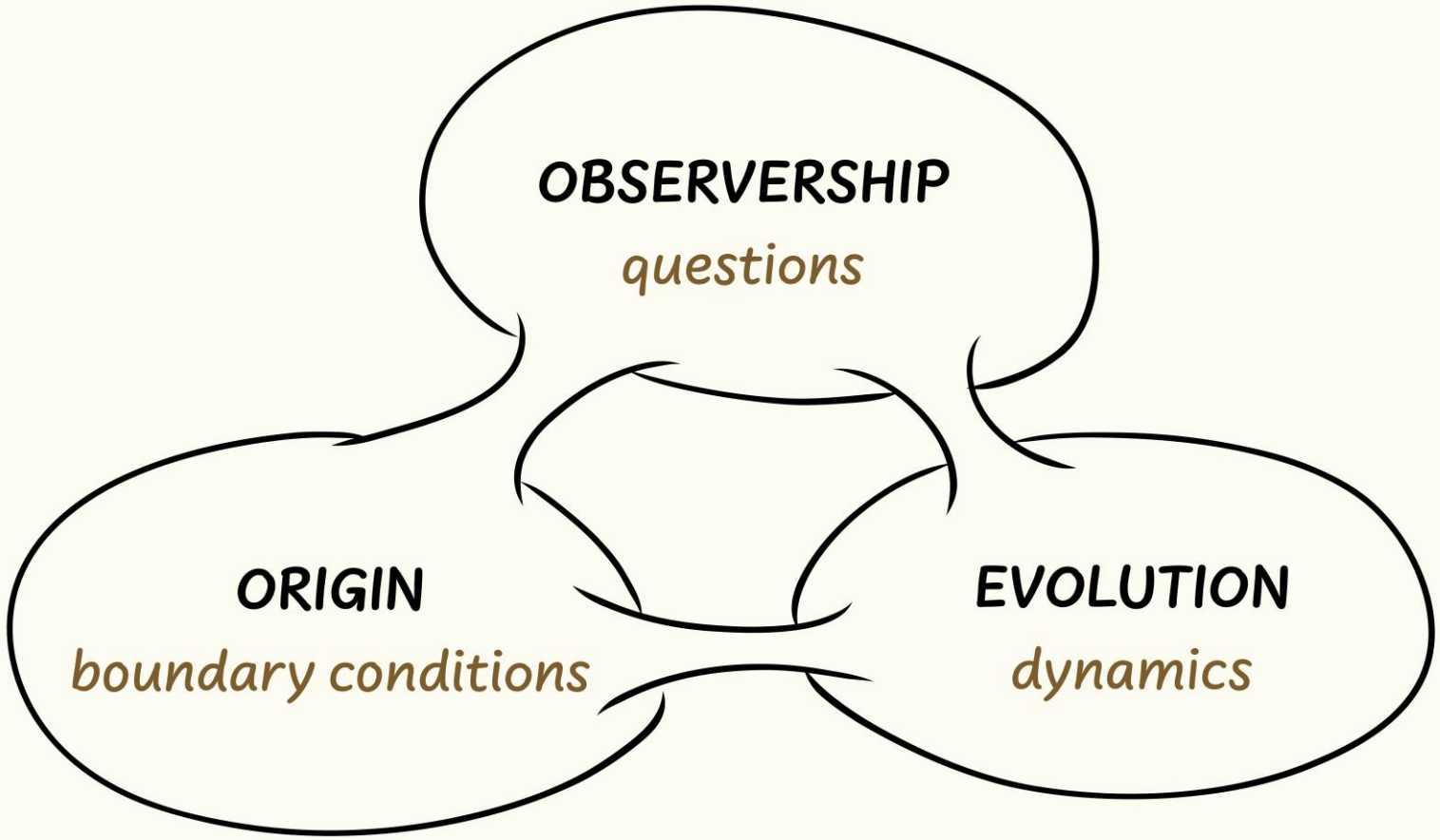
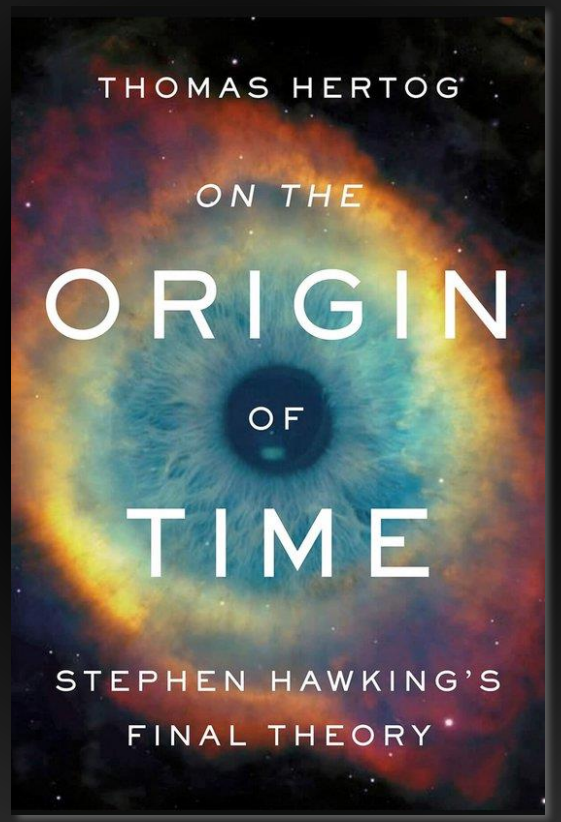
"If this suggestion is correct, the beginning of the world happened a little before the beginning of space and time."

"These considerations, besides providing a natural beginning, supply what can be called an inaccessible beginning… it stands just before Physics.

It is an inaccessible ground of Physics", an epistemic limit.


OBSERVERSHIP
questions
ORIGIN
boundary conditions
EVOLUTION
dynamics


THOMAS HERTOG
ON THE
ORIGIN
OF
TIME
STEPHEN HAWKING'S
FINAL THEORY

de Sitter entropy: microscopics

- Consider 11d Euclidean SUGRA on $-S^4 \times S^7/\mathbb{Z}_k$
- One-loop determinants generate log corrections to the free energy
- Odd dimensions: only zero modes contribute
- Massless 11d fields: metric, gravitino and three-form
- Ghosts are important!
- Metric and gravitino have no zero mode because S^4 is compact.
- Logarithmic correction due to a p-form:

$$\Delta F = \sum_j (-1)^j \left(\beta_{p-j} - j - 1\right) n^0_{\Delta_{p-j}} \log L/l_P, \qquad \beta_k = \frac{D-2k}{2}$$

- → $\Delta S_{dS} = 3 \log L/l_P$ $\qquad\qquad \mathcal{S}_{\rm dS} \overset{V}{=} -2 \log Z^{\rm ABJM}_{S^3}$