Baby Universes in Quantum Gravity

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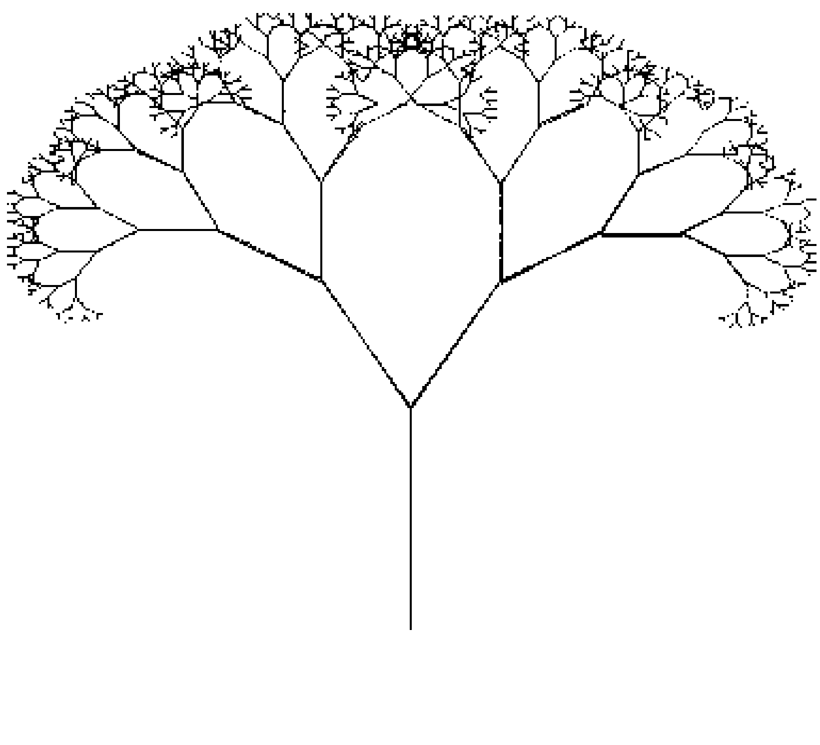

Pacific Institute of Theoretical Physics
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Weinberg-Witten Theorem

An interacting graviton cannot emerge from an ordinary QFT in the same dimensions.

PLB 96 1980

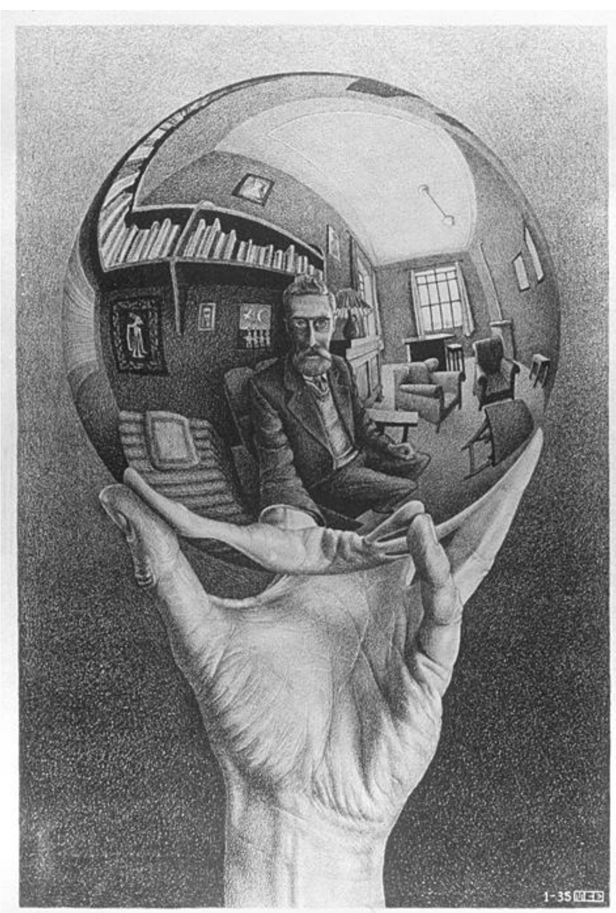
ordinary QFT

= any theory containing Lorentz covariant energy-momentum tensor

However ...

A quantum gravity can emerge simultaneously with spacetime.

A graviton in n dimensions may emerge from an ordinary QFT in m dimensions when n > m.



This allows a holographic description of quamtum gravity.

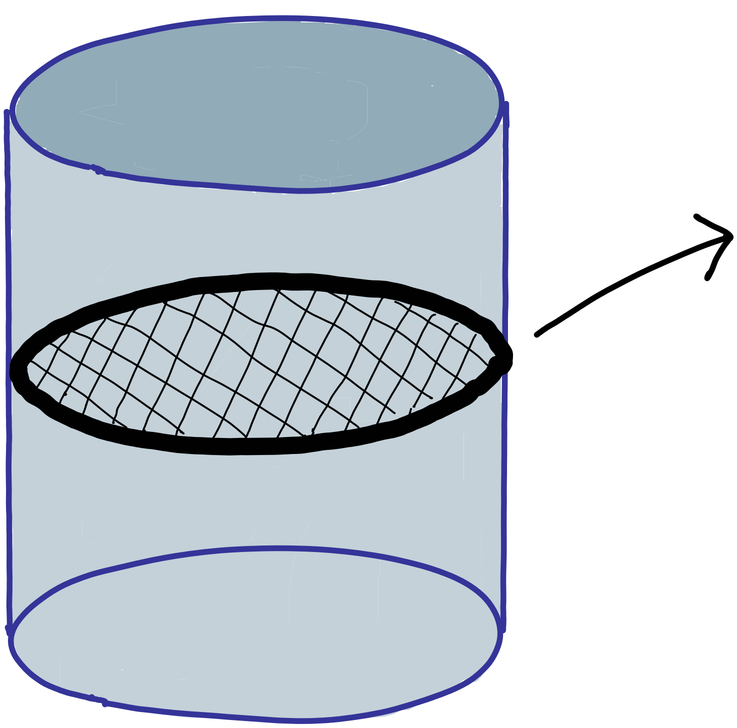
't Hooft 1993
Susskind 1994

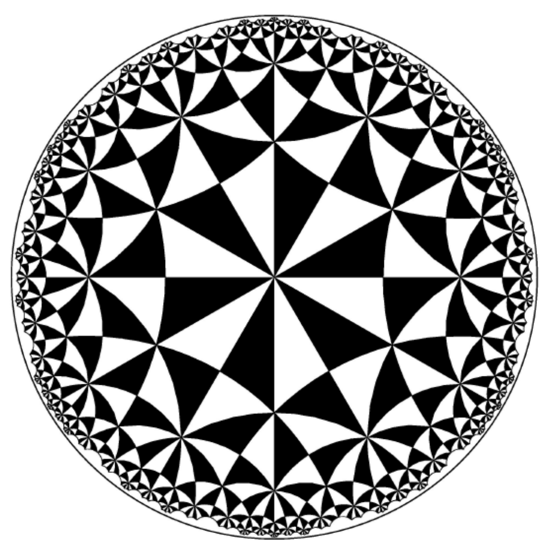
AdS/CFT correspondence is an example of holography.

Maldacena 1997

AdS = anti de Sitter space

Think of it as a solid cylinder.



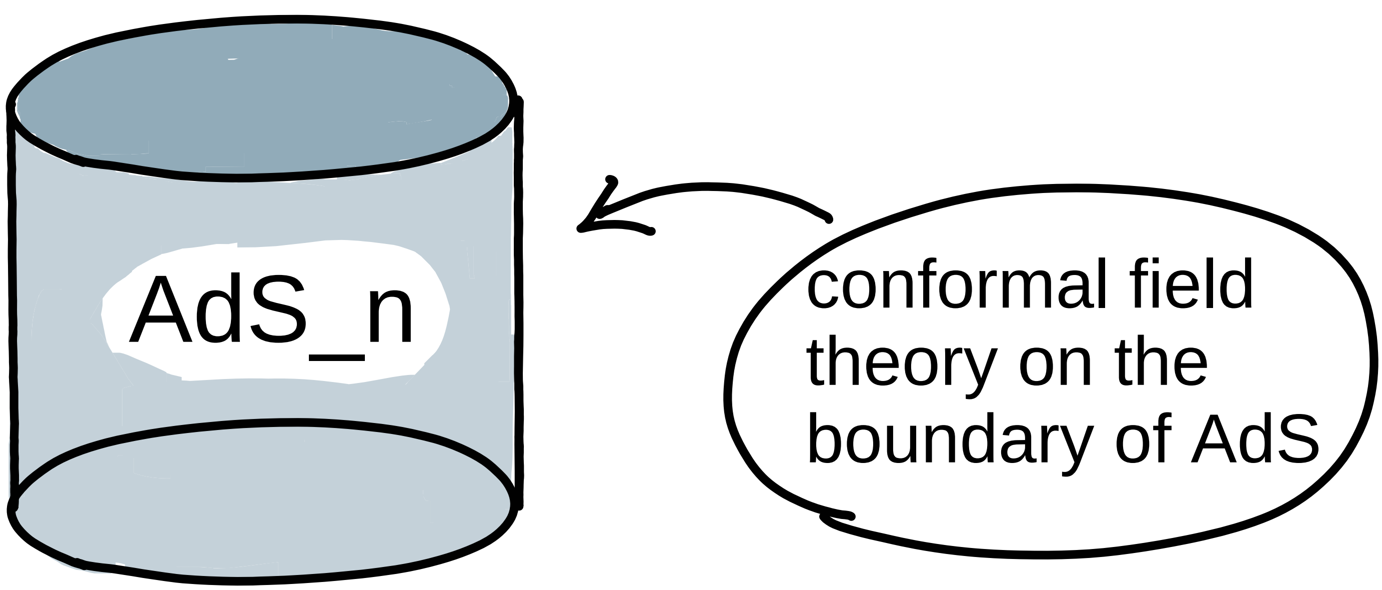


Spacelike section is a hyperbolic space.

AdS_n / CFT_{n-1}

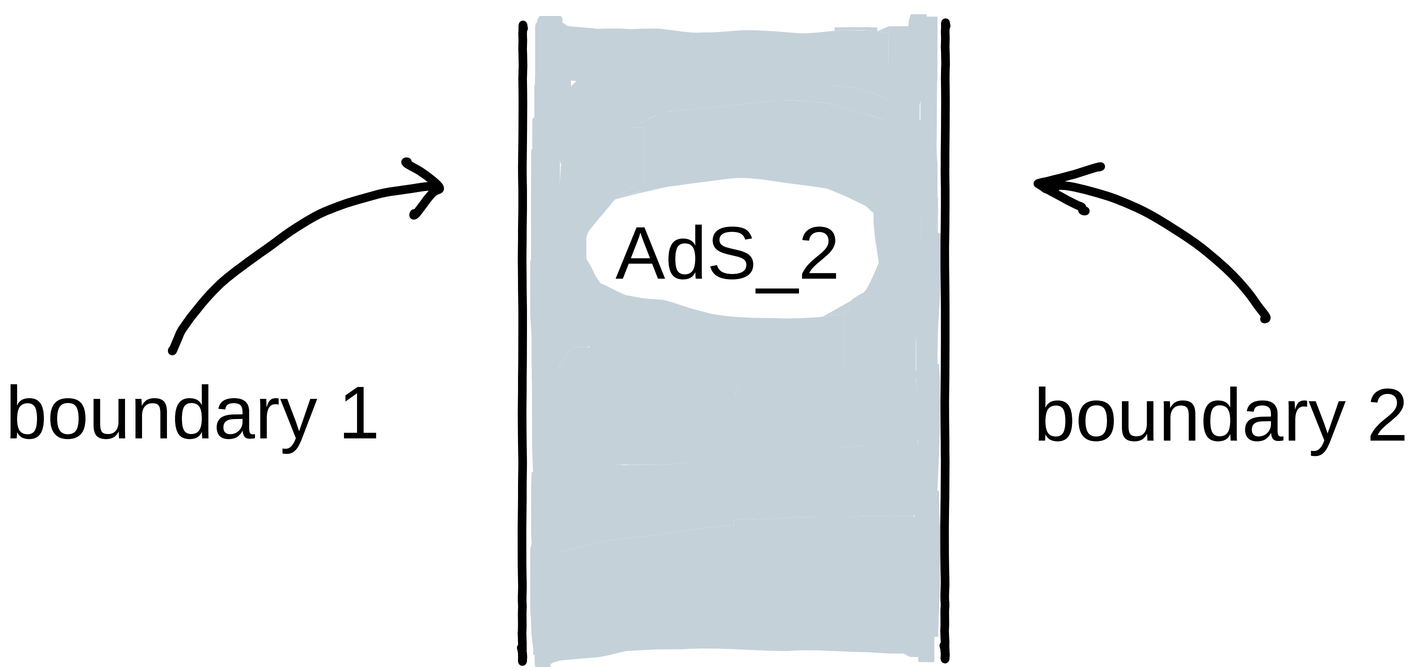
Superstring theory on
n-dim anti de Sitter space
times a compact space

is equvalent to
a conformal field theory
in (n-1) dimensions.



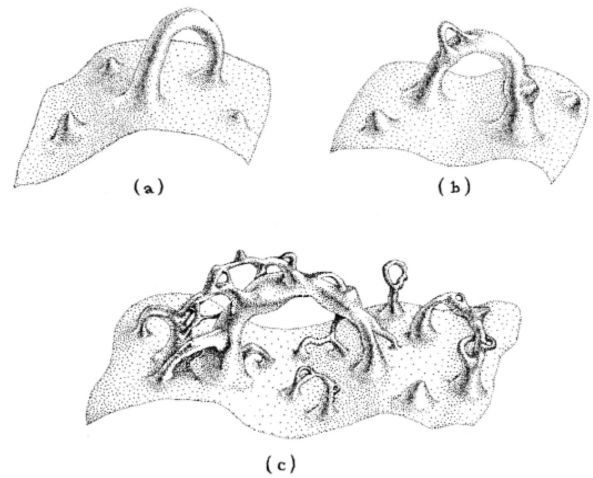
Later we will consider
2-dimensional AdS.

AdS_2 has two boundaries.

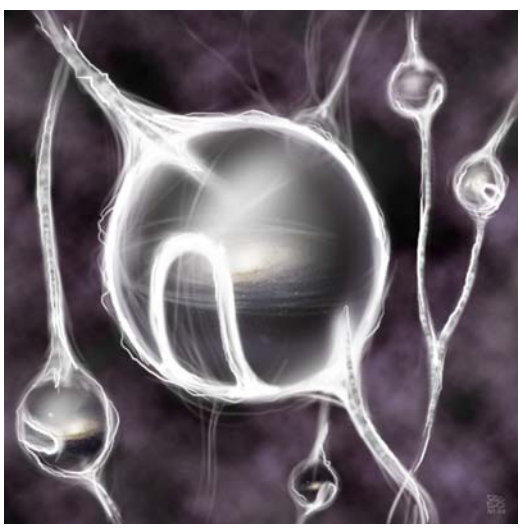


Questions:

Does the quantum gravity involves a sum over topologies of spacetime?



How about a sum over disconnected components of spacetime?



--- baby universes?

Can we maintain the unitarity and the quantum coherence?

We studied these questions in the following solvable example.

Dijkgraaf, Gopakumar, Vafa + H.O. hep-th/0504211

The holographic theory

= N non-relativistic free fermions on a circle

$$H = \sum_{i=1}^{N} \frac{1}{2} p_i^2$$

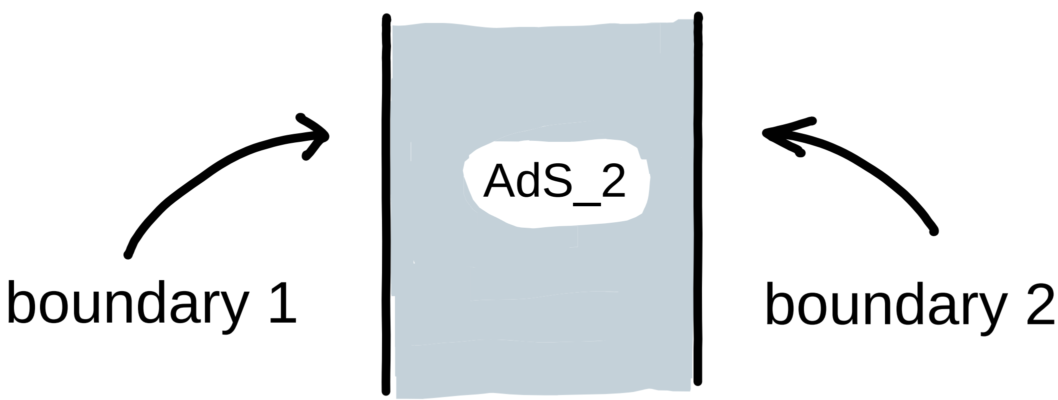
$$p_i = \pm\frac{1}{2}, \pm\frac{3}{2}, \pm\frac{5}{2}, \ldots$$

In this case, the gravity theory is type II superstring theory on

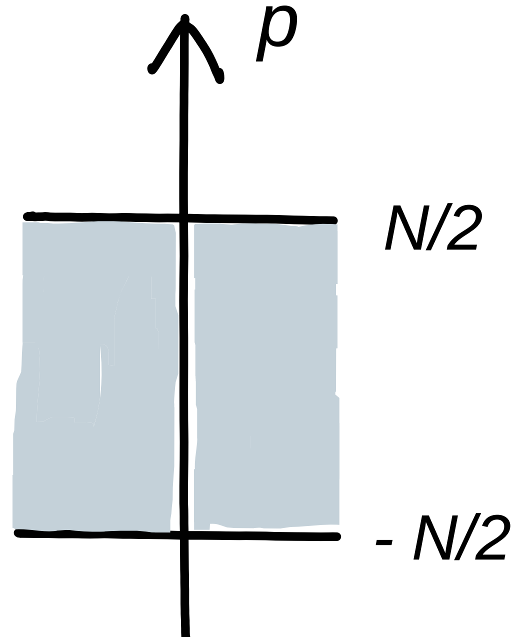
AdS_2 x S_2 x CY_3

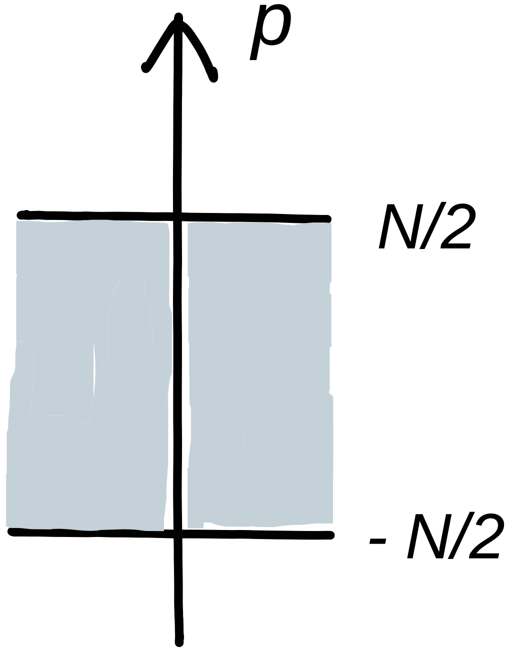
2d anti de Sitter — 2d sphere — 6d Calabi-Yau

AdS_2 has two boundaries.



This is dual to the fact that the *N* fermion theory has two fermi surfaces.





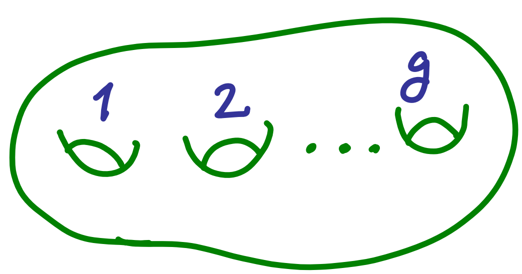
When *N* is large, the two fermi surfaces decouple from each other.

In the large *N* limit, fluctuations of each fermi surface are described by free relativistic fermions.

The *1/N* expansion of the non-relativistic free fermion partition function correctly reproduces the string perturbation theory

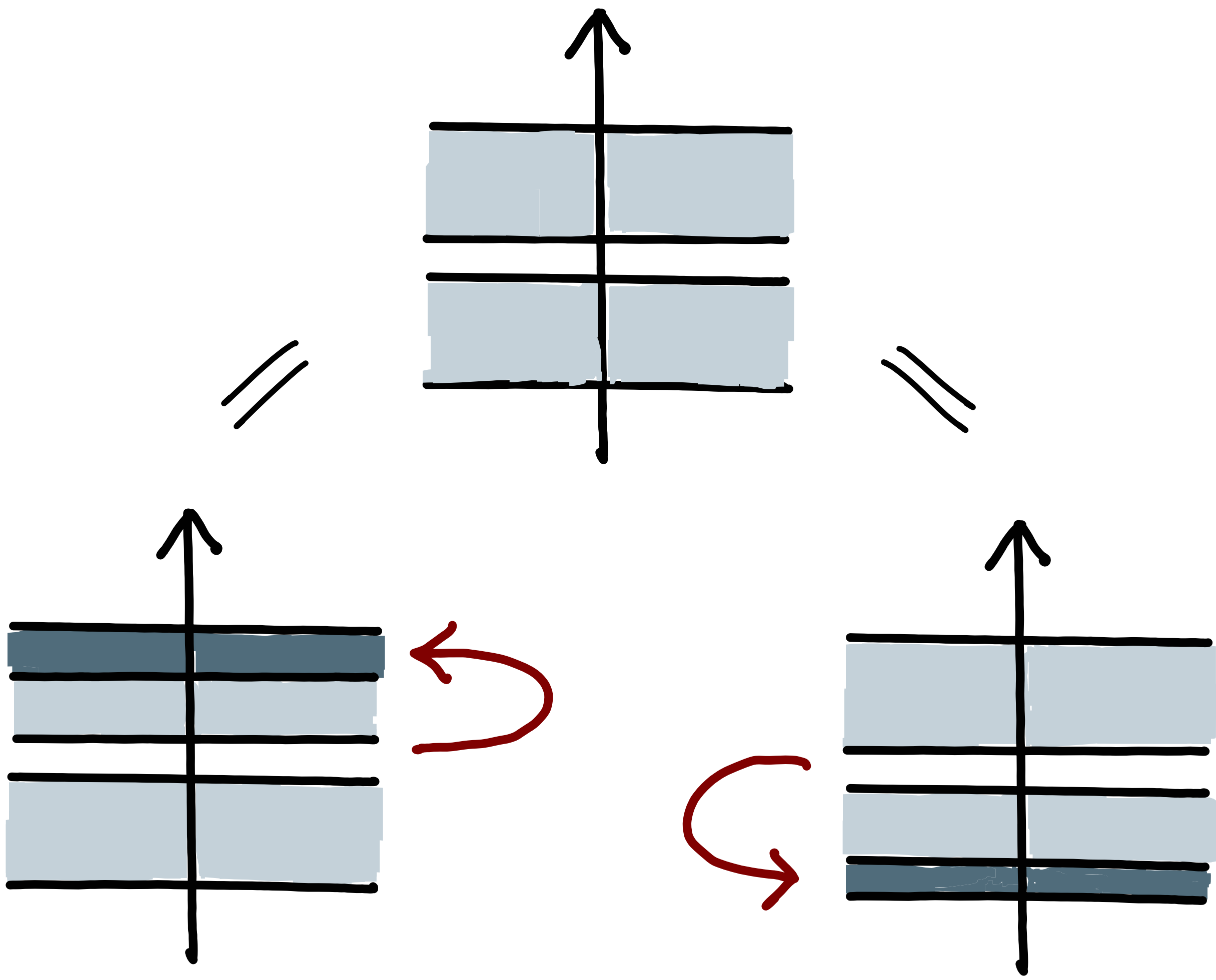
in AdS_2 x S_2 x CY_3

$$\exp\left(\sum_{g=0}^{\infty} \frac{1}{N^{2g-2}} \right.$$



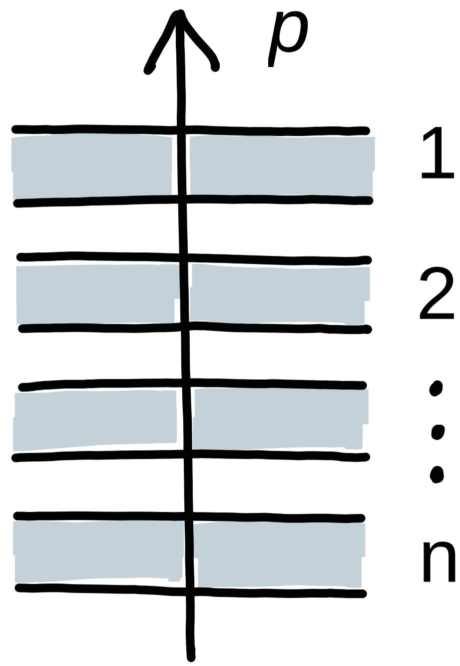
$$\left. \right)$$

For finite *N*,
the two fermi surfaces are entangled by excitations that are non-perturbative in *1/N*.

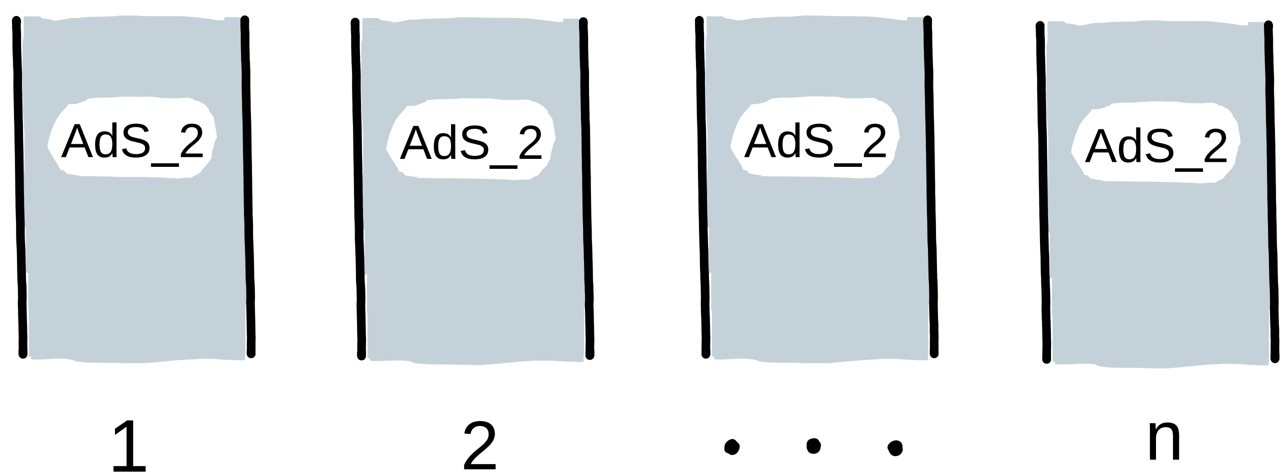


These non-perturbative states would be over-counted if we ignore the entanglement of the two fermi surfaces.

Configurations with 2n fermi surfaces



is dual to n disjoint universes



weighted by the Catalan number of planar binary trees with n branches (remembering how baby universe have been created from the parent universe).

Lessons for Quantum Gravity

In this example, the *1/N* expansion of *N* non-relativistic free fermions correctly reproduces the perturbative string theory.

In the fermion theory, $O(e^{-N})$ effects entangle two fermi surfaces.

In the gravity theory, they correspond to creation of baby universes.

Unitarity of quantum gravity can be maintained after we sum over topologies (including sum over disjoint universes).

This would be relevant for the black hole information paradox.

Baby universes do not destroy quantum coherence, in accord with a general argument by Coleman.

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