de Sitter Holography with Higher Spin Gravity

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Motivation

de Sitter has many puzzles, classical and quantum:

- definition of observables
- perturbative and non-perturbative stability
- entropy of the de Sitter horizon
- etc.

The Goal

In this talk I will describe a consistent theory of gravity in de Sitter space, and 'solve' it.

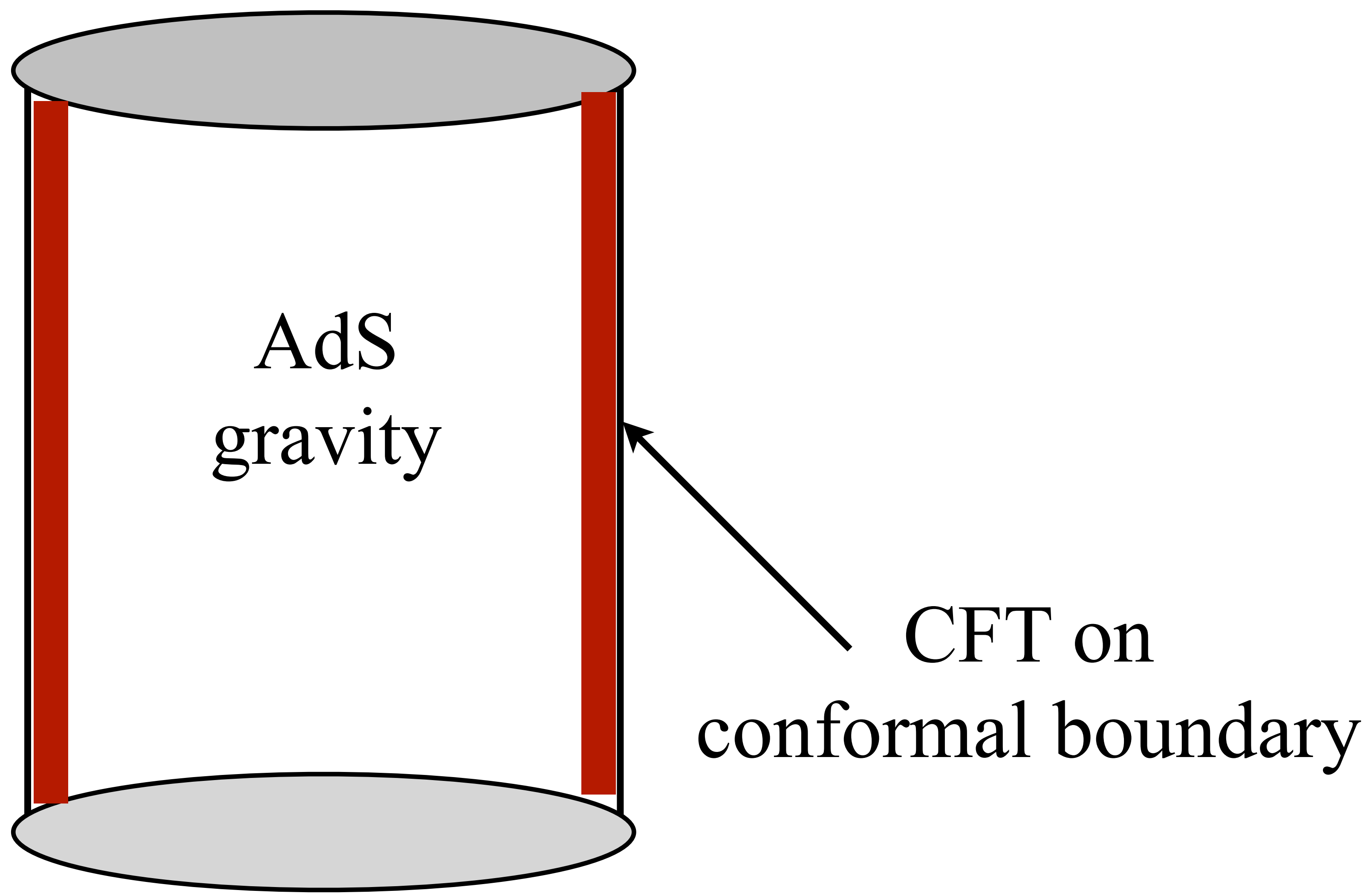
- Non-perturbative quantum gravity
- UV-complete
- Interacting but exactly solvable

however,

- It is a toy model
- In addition to gravity, it has an infinite number of massless particles of spin > 2
- (But is smaller than a string theory)
- meaning of "solve" is limited

Introduction

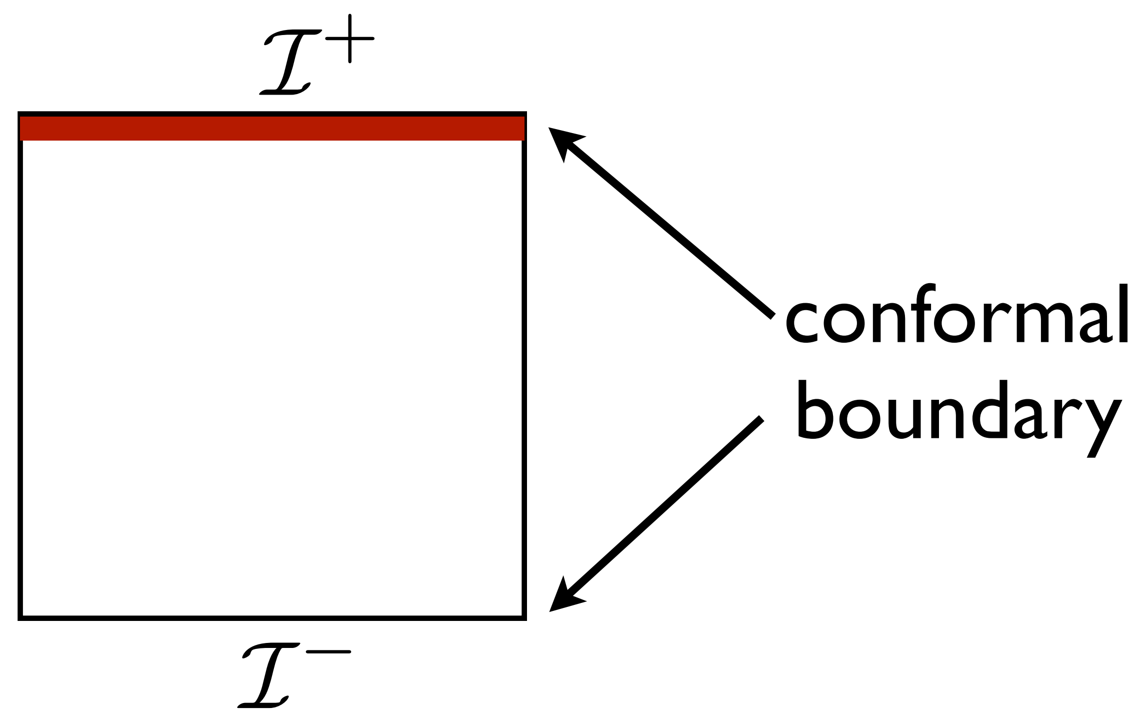
The AdS/CFT correspondence provides a non-perturbative definition of quantum gravity with negative cosmological constant.



But we live in (asymptotically) de Sitter space, in the past and future.

Introduction

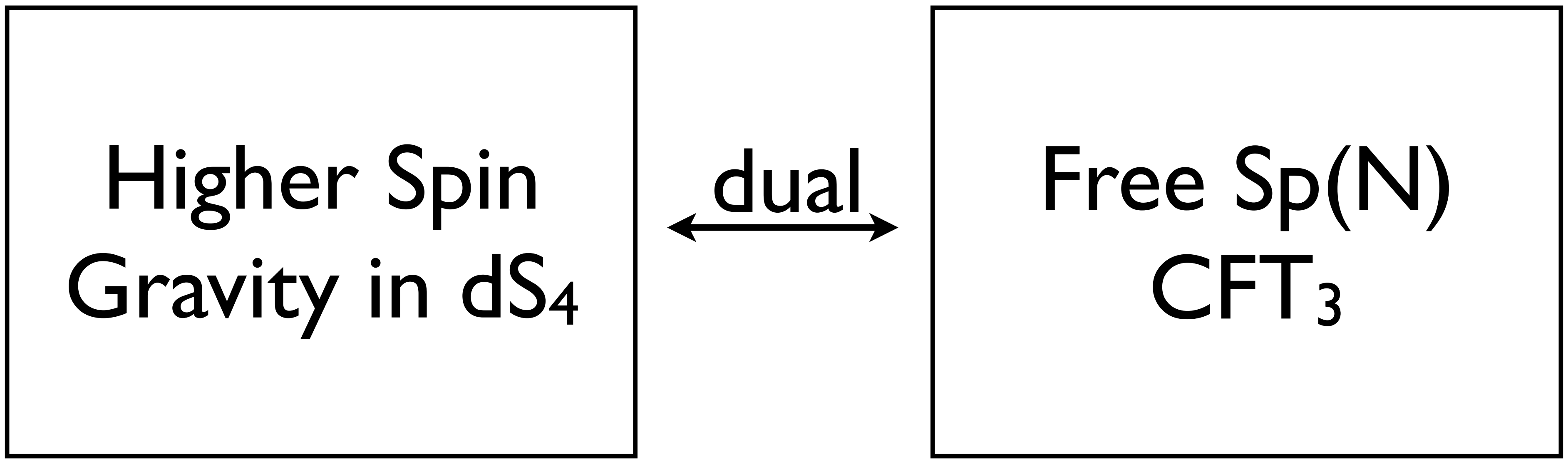
The dS/CFT correspondence, if it exists, is very different from AdS/CFT. Time is emergent:



A general dS/CFT dictionary has been proposed, but an explicit example was lacking.

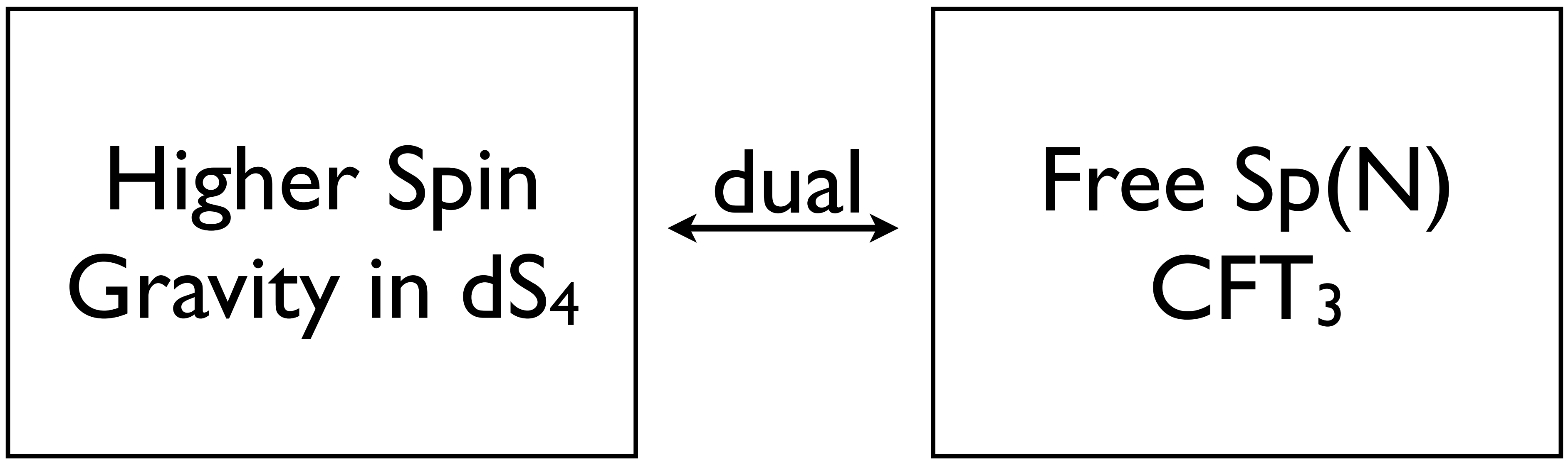
Witten '01; Strominger '01; Maldacena '02.

Introduction



$$\Lambda \sim 1/N$$

Introduction



$$\Lambda \sim 1/N$$

Outline of the talk

- Higher spin gravity
- The Sp(N) CFT
- Duality

I. Higher Spin Gravity

Higher Spin Gravity

Gravity plus large (or infinite) number of massless fields,

$$A_{\mu_1 \cdots \mu_s}$$

with spins

$$s = 0, 1, 2, 3, 4, \cdots ,$$

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Gravity plus large (or infinite) number of massless fields,

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with spins

$$s = 0, 1, 2, 3, 4, \cdots ,$$

Spin-2 = graviton. Massless higher spin fields mean very large gauge symmetry extending diffeomorphism invariance.

Consistent interacting theory exists for $\Lambda \neq 0$

Fradkin and Vasiliev, 1987
Vasiliev, 1990

Equations of HS Gravity

The equations of motion are known, but very complicated.

The action is unknown, but has higher-derivative interactions of the schematic form:

$$S \sim \int \frac{1}{\Lambda^{\#}} \partial^n X \partial^m Y \partial^k Z \cdots$$

$\Lambda \ell_P^2$ is the only parameter.

Reasons for Higher Spin

- This is a limit of string theory, where the string tension is taken to zero (i.e. on very small geometry). So it is a testing ground for quantum gravity in the stringy regime.

- It has a simple holographic description: Free fields!

  - the higher spin gauge fields have a dual description as the conserved currents in free field theory,

$$A_{\mu_1 \cdots \mu_s} \quad \leftrightarrow \quad \phi \partial_{(\mu_1} \ldots \partial_{\mu_s)} \phi$$

II. The Sp(N) CFT

The 3d Sp(N) Model

N free anticommuting scalars ("ghosts")

$$S_{cft} = \frac{1}{2} \int d^3x \; \Omega_{ab} \, \partial\chi^a \cdot \partial\chi^b$$

$$\Omega \equiv \text{antisym. symplectic form}$$

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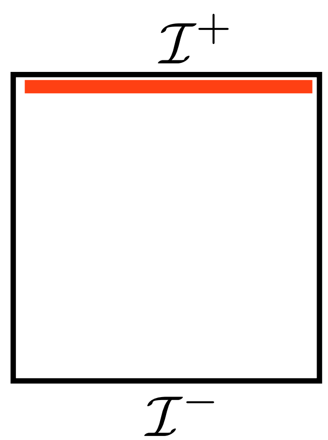
- In Lorentzian signature, this would be non-unitary.
- Our CFT is Euclidean; unitarity is not an issue.
- Nonetheless unitarity of the gravitational theory should be encoded somehow in the CFT.



Currents

The Sp(N) model has a conserved current of every even spin:

$$J_{\mu_1 \cdots \mu_s} = \Omega_{ab} \chi^a \partial_{(\mu_1} \cdots \partial_{\mu_s)} \chi^b + \cdots$$

We restrict to the singlet sector (by gauging and sending the gauge coupling to zero).

Then at large N, these currents are the only local operators of small dimension. This is precisely the spectrum of higher spin gravity.

The Claim

Higher spin gravity in dS_4 = Sp(N) CFT

$$\Lambda \sim \frac{1}{N}$$

- Conjecture was based on 3pt correlators

  Anninos, TH, Strominger 2011

- Now proven for all n-pt functions to all orders in perturbation theory

  Maldacena, Zhiboedov 2011

O(N) duality

An AdS/CFT Example

- Higher spin gravity in AdS is dual to free bosons, ie the O(N) model

$$\phi^a \partial \cdots \partial \phi^a$$

Fronsdal '79
Witten
Sundborg
Mikhailov
Sezgin & Sundell
Klebanov & Polyakov
Giombi and Yin
...

- 3pt correlators were computed by Giombi and Yin

Petkou; Giombi and Yin

- The dS/CFT example in this talk is constructed by modifying this duality for use in de Sitter. This procedure does not work in string theory examples of AdS/CFT.

III. dS/CFT Duality

Statement of dS/CFT

In words:

The CFT computes the Hartle-Hawking/Bunch-Davies wavefunction of the gravity theory.

Statement of the Duality

The statement of dS/CFT is:

Witten '01
Strominger '01
Maldacena '02

$$\boxed{Z_{cft}[X_0] = \Psi_{grav}[X_0]}$$

$$= \int_{X_0} DX e^{iS_{grav}[X]}$$

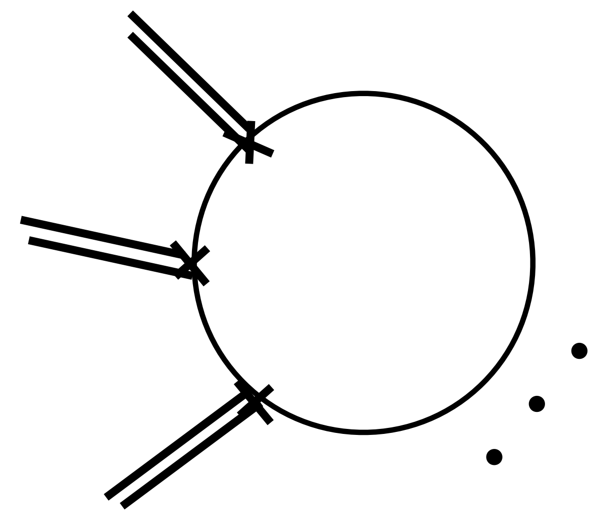
- X is a field in de Sitter
- X_0 is its value at the future boundary $\mathcal{I}^+$

$$X \sim X_0(x)\eta^{3-\Delta}$$

- In the CFT, X_0 is the source for the dual higher-spin current

Computing CFT Correlators

$$\langle J^{(s_1)} J^{(s_2)} \dots J^{(s_n)} \rangle_{cft} =$$



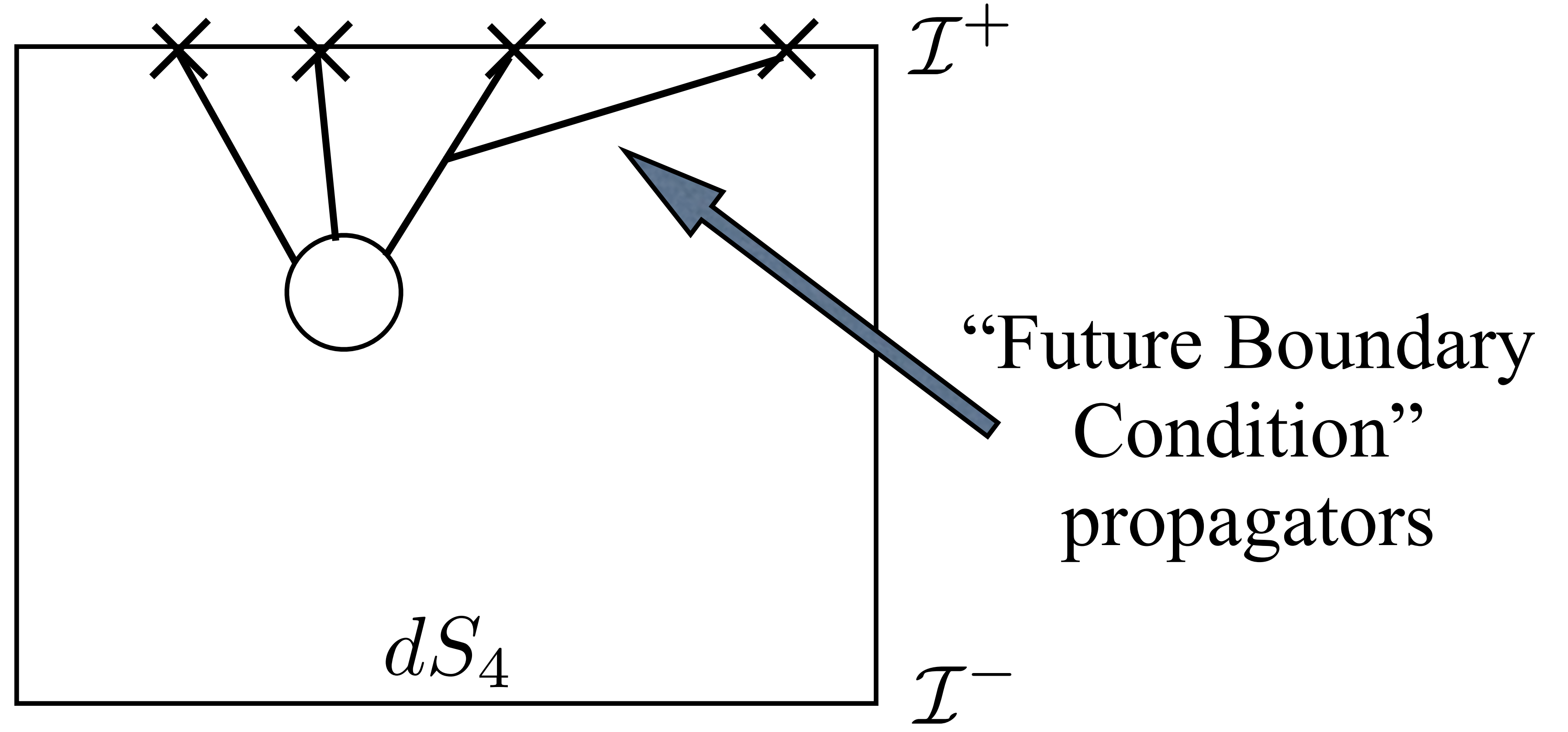
This is a trivial free-field Feynman diagram.

Computing the Bulk Wavefunction

Semiclassically, the HH wavefunction is

$$\Psi[X_0] \approx e^{iS_{bulk}[X_0]}$$

This can also be computed diagrammatically:



Aside: In-In

These are not In-In correlators. Maldacena '02

The wavefunction is only the first half of an In-In computation:

$$\langle X_1 X_2 \cdots \rangle_{in-in} = \int DX_0 |\Psi_{grav}|^2 X_1 X_2 \cdots$$

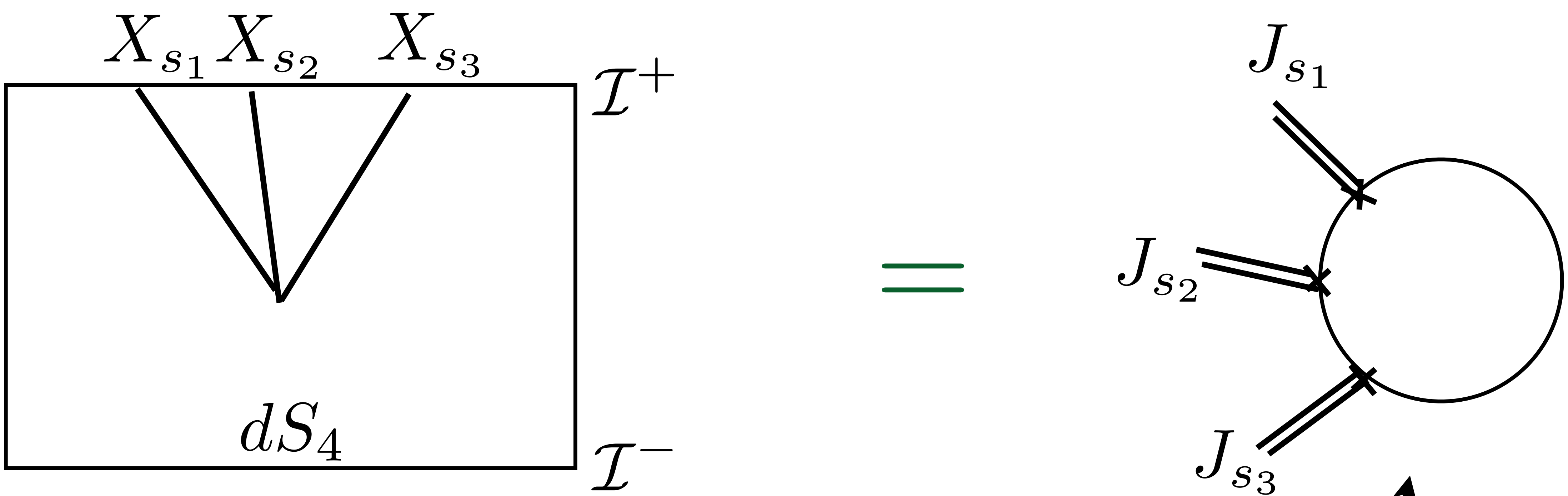
Therefore

$$\text{CFT correlators} \neq \text{gravity correlators}$$

To compute gravity correlators, you must allow fields to fluctuate at $\mathcal{I}^+$

Results

By explicit computation,



computed in
higher spin gravity

computed in
free Sp(N) CFT

Comments

- This is the cubic part of

$$Z_{cft}[X_0] = \Psi_{grav}[X_0]$$

- The most difficult part is finding the propagators and interaction vertices of higher spin gravity. This was done by Giombi and Yin in AdS; we analytically continued to produce de Sitter results.

$$N \to -N \ , \quad \Lambda \to -\Lambda$$

- Under some assumptions, Maldacena and Zhiboedov used constraints from higher spin symmetry to prove equality for all n-point correlators.

Conclusion

Higher spin gravity is dual to a free CFT and may allow a UV-complete holographic duality in de Sitter.

Things you might hope to compute:

- RG flows corresponding to universe production
- non-perturbative wavefunction of the universe
- de Sitter entropy
- static patch observables

Anninos, Denef, Harlow '12

Ultimately, seeking general rules for de Sitter holography.