Decoding the Hologram?

Introduction, overview, questions

Widespread belief: <u>Equivalence</u> of string theory in AdS, and CFT on ∂AdS.

If true, quantum gravity in AdS <u>defined</u> by CFT

How do we make this precise?

How do we use it to answer vexing bulk questions?

Eg. How is gravitational scattering unitarized?

Black hole info...

(Singular horizons...)

What is the precise statement of the AdS/CFT correspondence?

(cf. SBG 1105.6359)

If it's an equivalence, the obvious possibility:

$$\mathcal{H}_B \xrightarrow{M} \mathcal{H}_\partial$$

expect exists

$M =$
- 1–1
- onto
- unitary (isometric)

$\Rightarrow$ operator map: $\mathcal{O}_B = M^{-1}\mathcal{O}_\partial M$

$\Rightarrow$ relate evolution: $U_B = M^{-1} U_\partial M$

unitary

So, What is M?

— matching what we know

— meeting bulk expectations

What bulk quantities do we expect to construct ?

Leading candidates:

— S-matrix
(in flat limit)

in LQFT

— ~ Local Observables (cf Friday discussion)

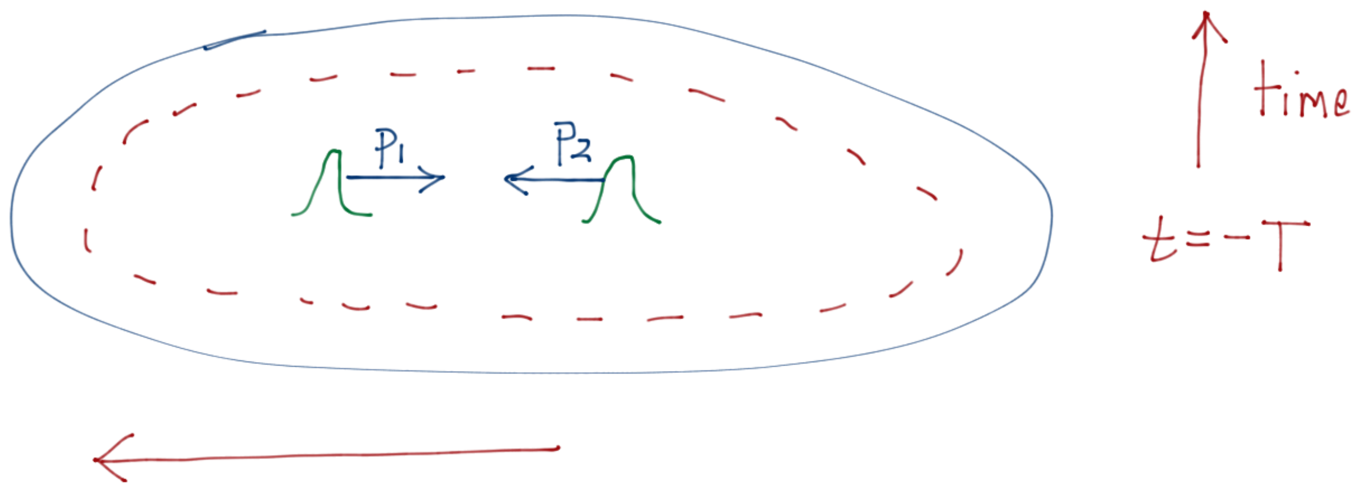
Discuss in turn ...

S-matrix

Starting point: <u>scattering states</u>

Eg. AdS:

$|\psi, -T\rangle$:



$R = \text{AdS radius} \overset{\text{e.g.}}{=} 10^{10}\ \text{lyear}$

- Really want multiparticle (complete set)

- Likewise for $t = T$

$$\Rightarrow \quad S_{\psi'\psi} \simeq \langle \psi', T | \psi, -T \rangle$$

Questions:

1) Can construct scattering states, from boundary data?
(i.e. in $\mathcal{H}_\partial$)

2) Does $S_{\psi'\psi}$ then $\simeq$ S_{LQFT}

when should

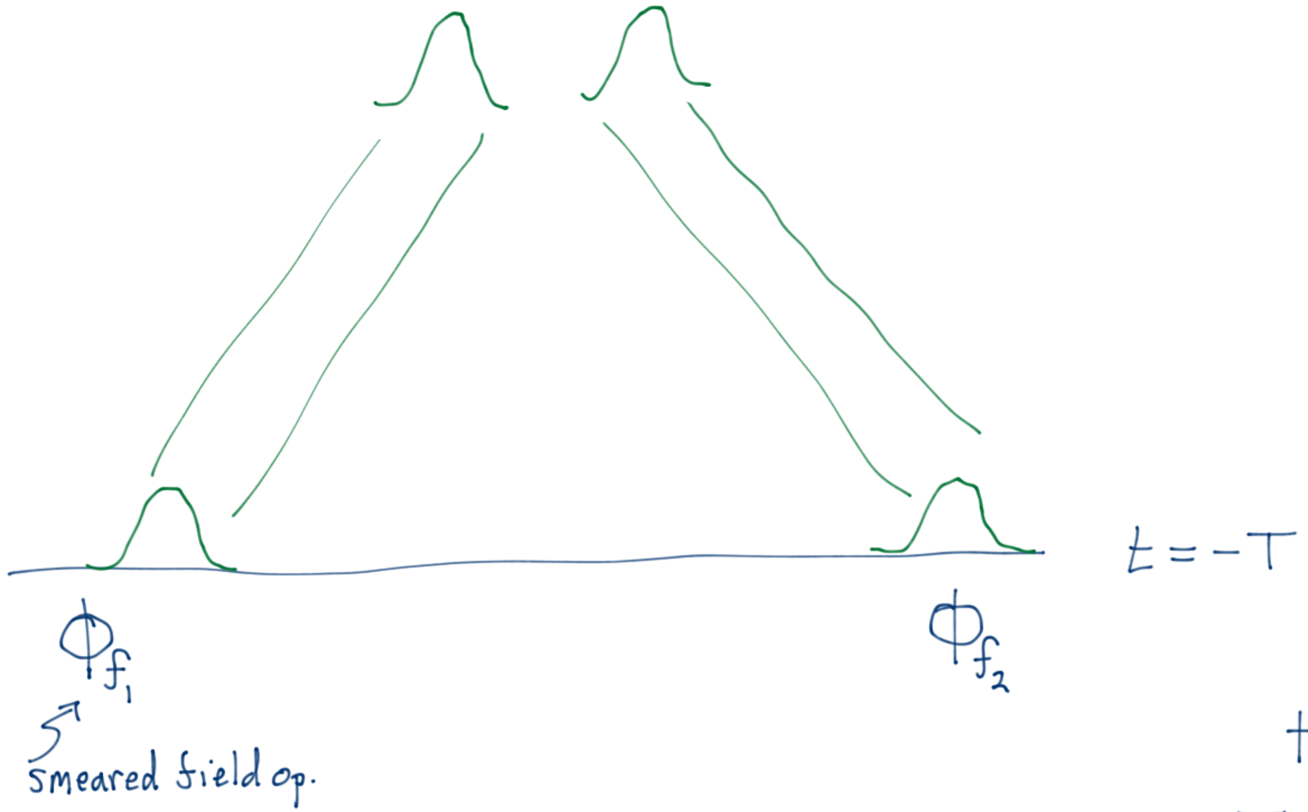
(and what does it say more generally?)

BHs, etc!

$$S_{\psi'\psi} \simeq \langle \psi', T \,|\, \psi, -T \rangle$$

Recall scattering states in <u>flat space</u> : LSZ

(nontrivial at first; then take for granted...)



take:

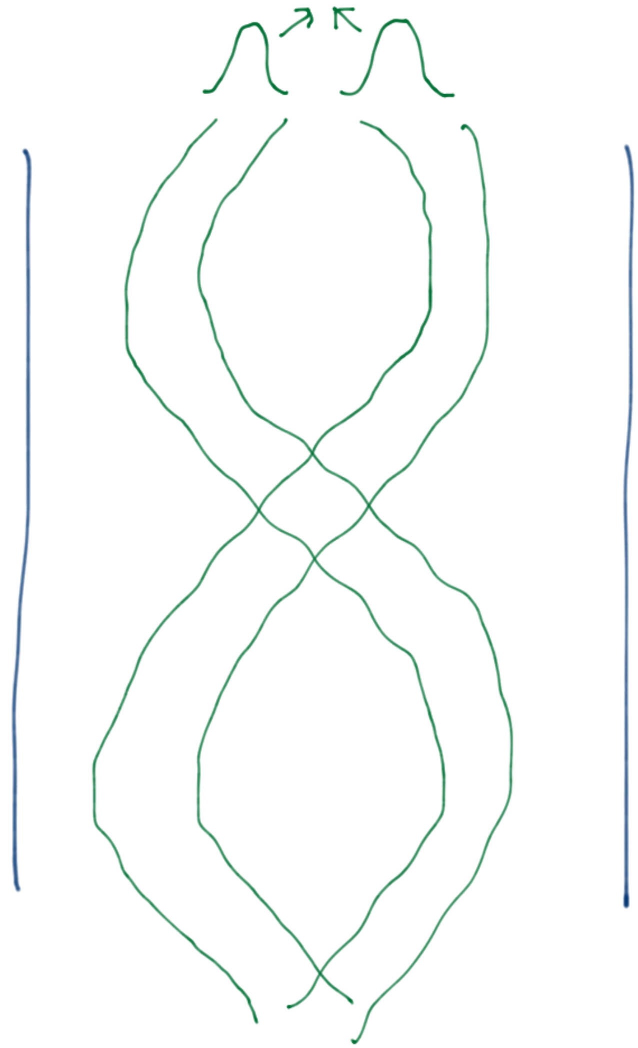
$-T \to -\infty$

"<u>interactions</u>" $\to 0$

Analog for AdS ?

AdS:

Normalizable states:



Isolation problem:

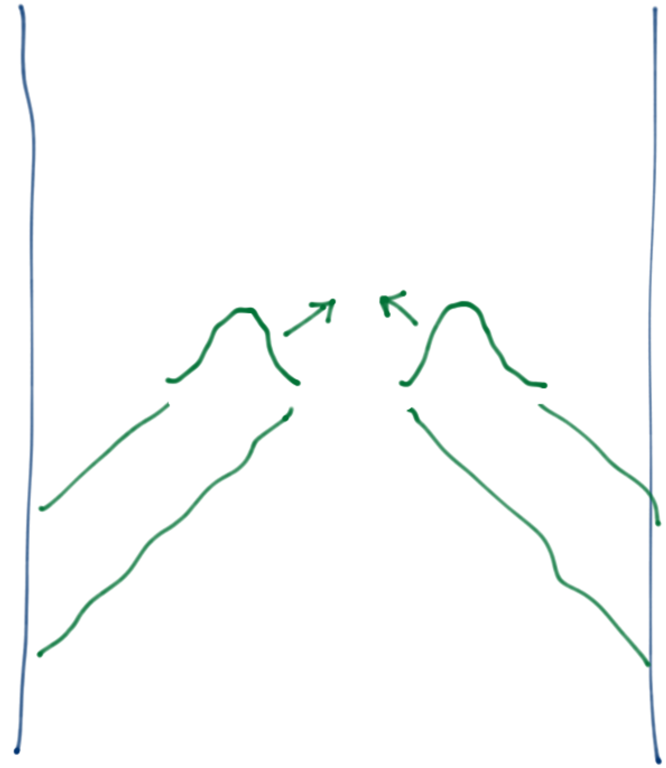
Can we isolate single scattering, using purely boundary construction?

Or, boundary thy $\longleftrightarrow$ <u>averaged</u> amplitudes?

(Note also: issues w/ pert. expansion in g ...)

Alternative: wavepackets from boundary:

$$\int db\, f(b)\, \mathcal{O}_\partial(b)$$

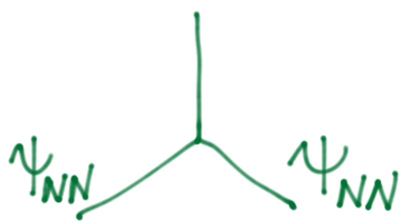


Potential problem:

∞ potential barrier $\Rightarrow$

∞ amplitude needed : Ψ_{NN} $\leftarrow$ Nonnormalizable

$\rightsquigarrow$ can have interactions near ∂: (∞ or finite)



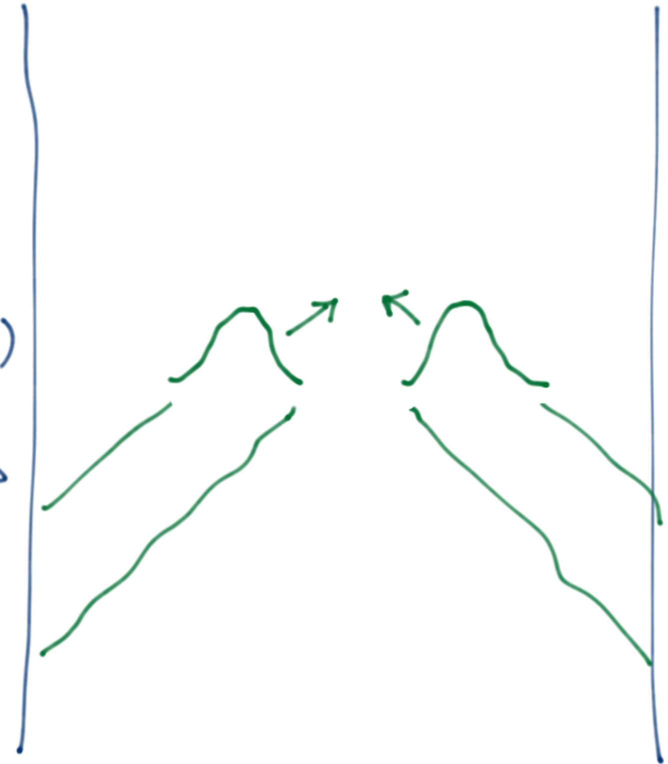
Again, isolation problem?

For noncompact $f(b)$'s, can occur anywhere.

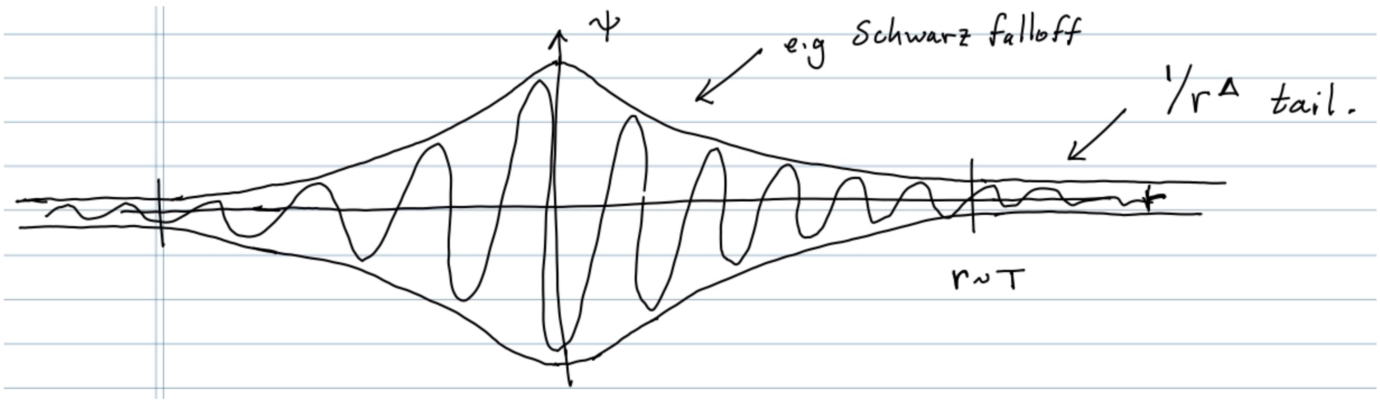
(SBG hep-th/9907129)

Or: compact $f(b)$:
"Boundary compact"
(Gary, SBG, Penedones; Gary, SBG)

$\int db\, f(b)\, \mathcal{O}_\partial(b)$



Restrictions on wavepackets; ⇝
Don't have arbitrary wavepackets;
Can't construct full space of scattering states?
In particular, power law tails.



But: want better localization / exponential sensitivity.

In conclusion:

Don't know can identify good scattering states in $\mathcal{H}_2$.

Also, certain singularity structure needed in correlators, to produce δ- fcn, poles etc. of S-matrix.

(Gary, SBG, Penedones)

Is it present in $\mathcal{N}=4$ SYM ?

... Zhiboedov

A related approach: Mellin amplitudes

Mack; Penedones; Fitzpatrick-Kaplan; van Rees; ...

Mellin amp.

$$\langle \mathcal{O}(x_1)\cdots\mathcal{O}(x_n)\rangle = \int [d\gamma]\, M(\gamma_{ij}) \prod \Gamma(\gamma_{ij})\,(x_{ij})^{-\gamma_{ij}}$$

Mellin variables

Simple cases: (when can find M, uniquely)

$$T(s_{ij}) = \int d\alpha\, e^{\alpha}\alpha^{p}\, M\!\left(\gamma_{ij} = -\frac{R^2 s_{ij}}{\alpha}\right)$$

<u>Reduced</u> T matrix $\neq$ S-matrix

I.e. can read off (some) couplings of bulk EFT, if assume we have a bulk EFT.

But: doesn't construct full bulk quantum theory?

want $\mathcal{H}_\partial$ etc $\longrightarrow$ $\mathcal{H}_B$, $\mathcal{O}_B^i$, U_B

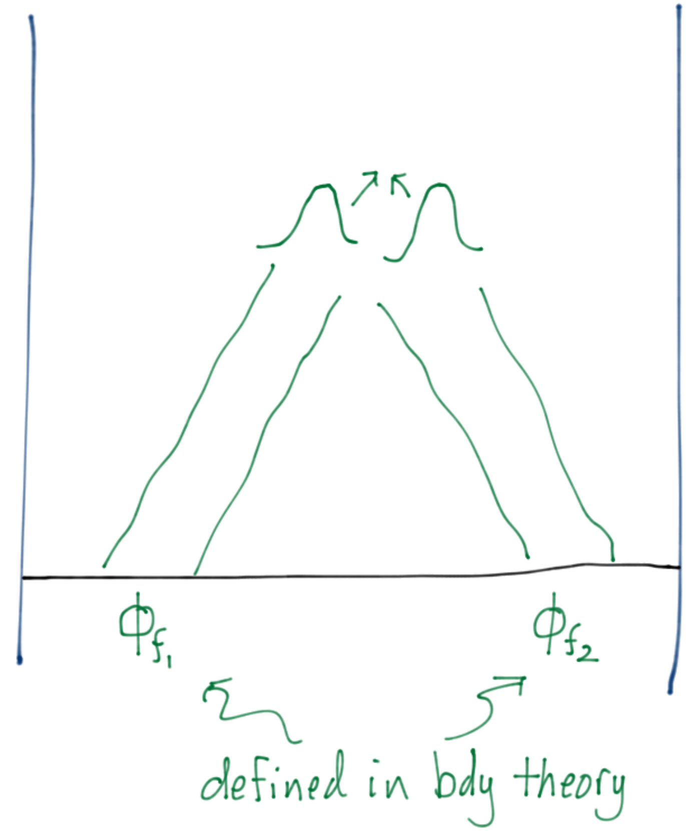
(full quantum theory, not EFT...)

... limited success?

... Update from Fitzpatrick

Construct ~local bulk observables?

If we have, $\rightsquigarrow$



but even better?
(inside BHs, etc...)

But: What operators constructed ?

recall Friday discussion:

What are good "gauge invariant" operators ? Dressing, etc.
(~diff)

An approach; perturbative in g ($\sim 1/N$)

BDHM BGL B HKLL HMPS KL ...

First, free level ($g=0$):

$$\phi(x) \xrightarrow[x\to\partial]{} \frac{1}{x^{\Delta}}\,\mathcal{O}(b)$$

Green fcn/
Green's theorem

$$\phi(x) = \int db\, K(x,b)\, \mathcal{O}(b)$$

"smearing function"

Not too surprising it works at $g=0$ ...

$g \neq 0$?

Iterate, using bulk EOM (HKKL, HMPS ...)

e.g. $(\Box - m^2)\phi = g\phi^2$ $\quad (*)$

$\rightsquigarrow$ Green's thm.

Expect

$$\phi(x) = \underbrace{\int db\, K(x,b)\,\mathcal{O}(b)}_{\text{Leading term}} + \underbrace{g\int dx'\, G(x,x')\,\phi^2(x')}_{\text{Small correction}}$$

Then iterate.

Note in $(*)$, ϕ = normalizable : $\xrightarrow[x\to\infty]{} 0$

But: $\int dx'\, G(x,x')\,\phi^2(x') =$ <u>nonnormalizable</u>

$\xrightarrow[x\to\infty]{} \infty$

So, "leading" and "small" both divergent; divergence cancels

How can this yield a systematic pert. expansion ?

Possible critique of "operator" program:

1. No canonical procedure, intrinsic to bdy theory, indep of solving bulk eqs. of motion.

   (Though KLL – "enforce locality"?)

2. Trouble with systematics of expansion (no good small parameter)

3. Question of what gauge-invariant operators

   ... update: Kabat

4. Puzzles re. "different realizations" of $\phi(x)$

   e.g. different AdS/Rindler patches

→ "Error correcting codes" Almheiri, Dong, Harlow

Pastawski, Yoshida, Harlow, Preskill

"Gauge symmetry" Mintun, Polchinski, Rosenhaus

(How) Can we decode the hologram?

- a very important question
- still an unsettled question

What is an alternative, given success of AdS/CFT at <u>boundary</u> predictions?

Proposal:

$$\mathcal{H}_B \xrightarrow{M} \mathcal{H}_\partial$$

M "coarse grains" $\mathcal{H}$ and/or dynamics

SBG hep-th/9907129
SBG + Lippert
SBG + Gary

Marolf-Wall

"Symmetry + universality" → Many shared features of bulk & bdy.