Title: Quantum Information and holography

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Collection: Quantum Information and holography (2021/2022)

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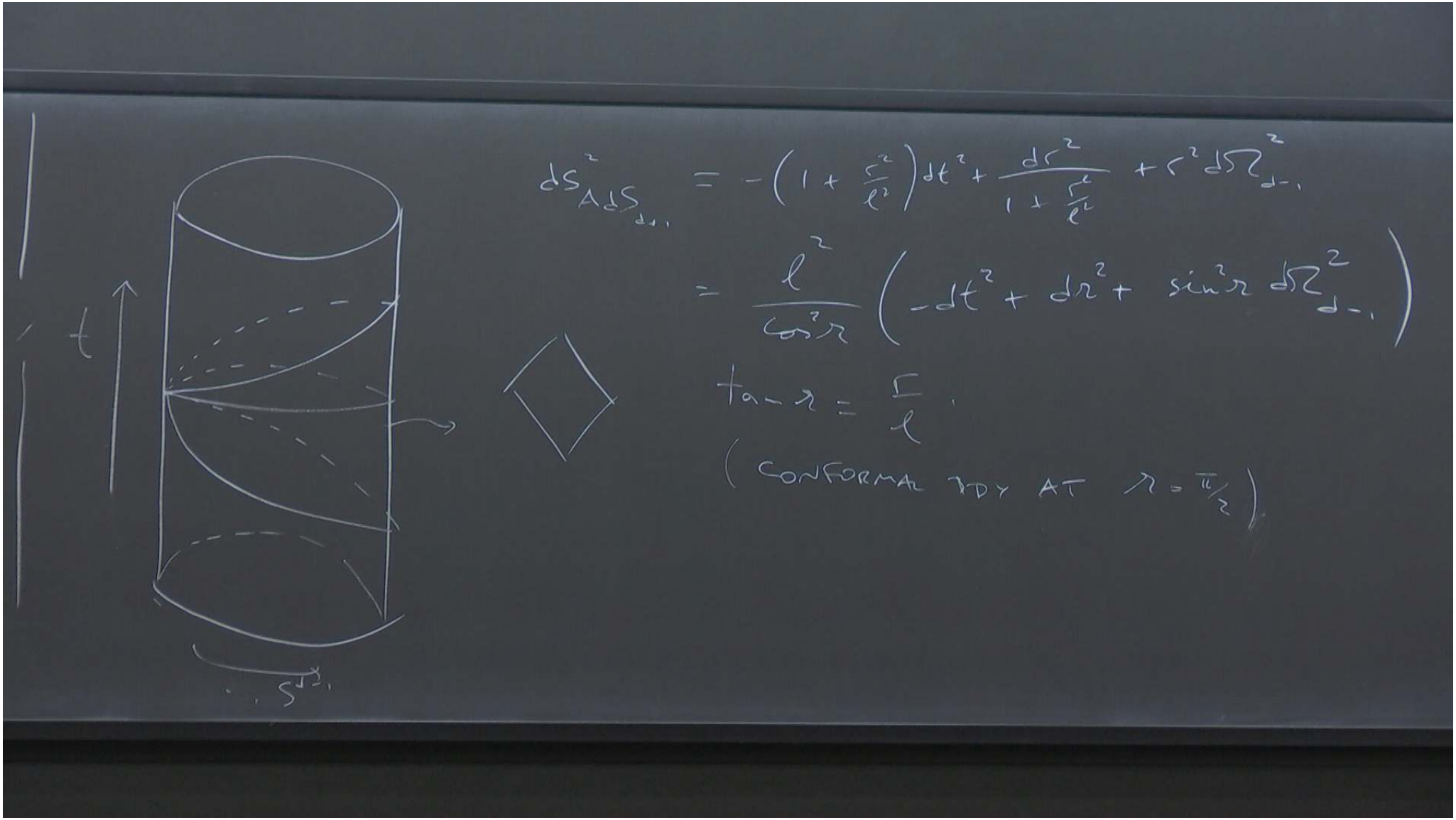
Abstract: Topics will include (but are not limited to):
- Quantum error correction in quantum gravity and condensed matter
- Quantum information scrambling and black hole information
- Physics of random tensor networks and random unitary circuits

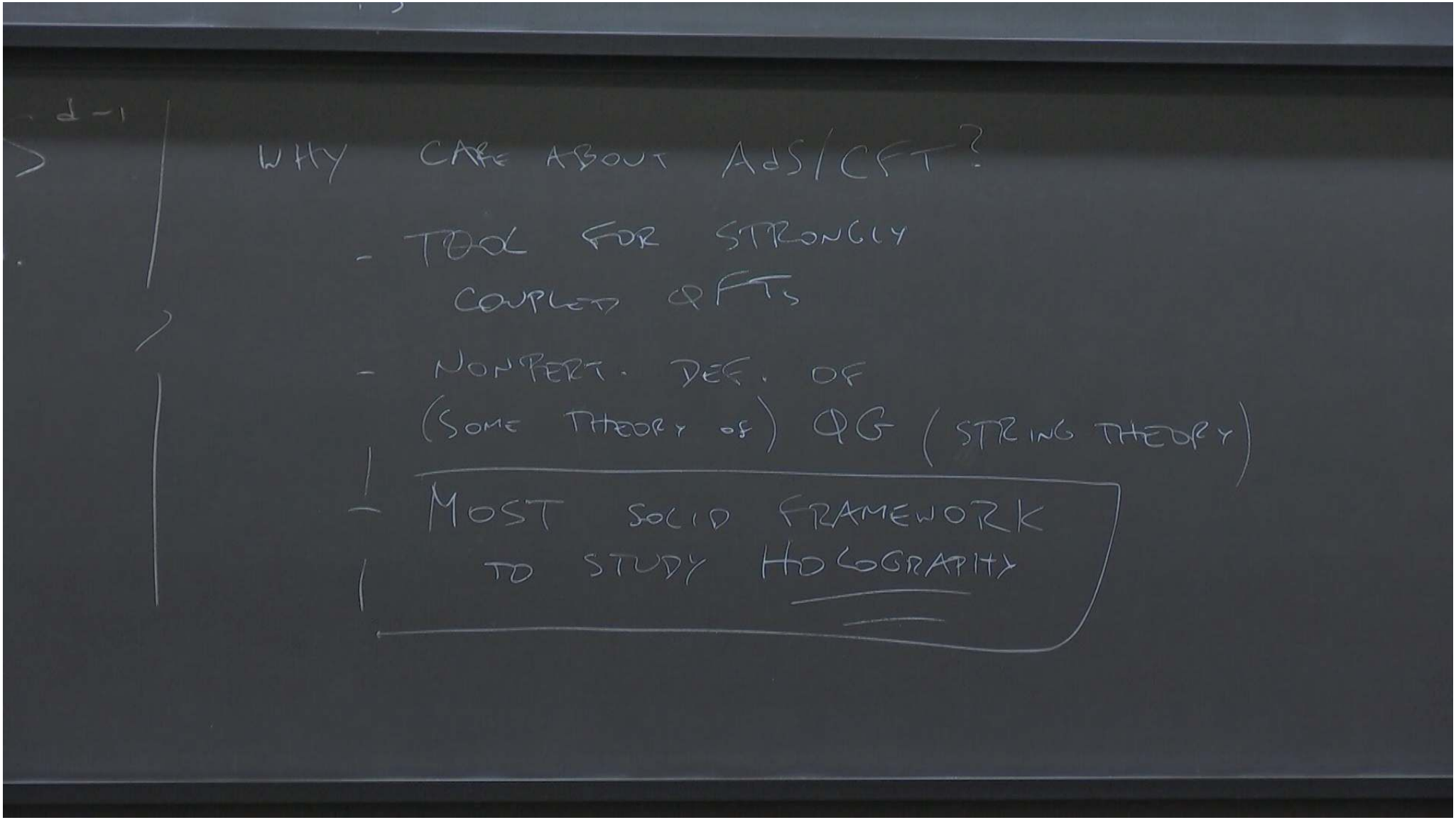
# QI & HOLOGRAPHY

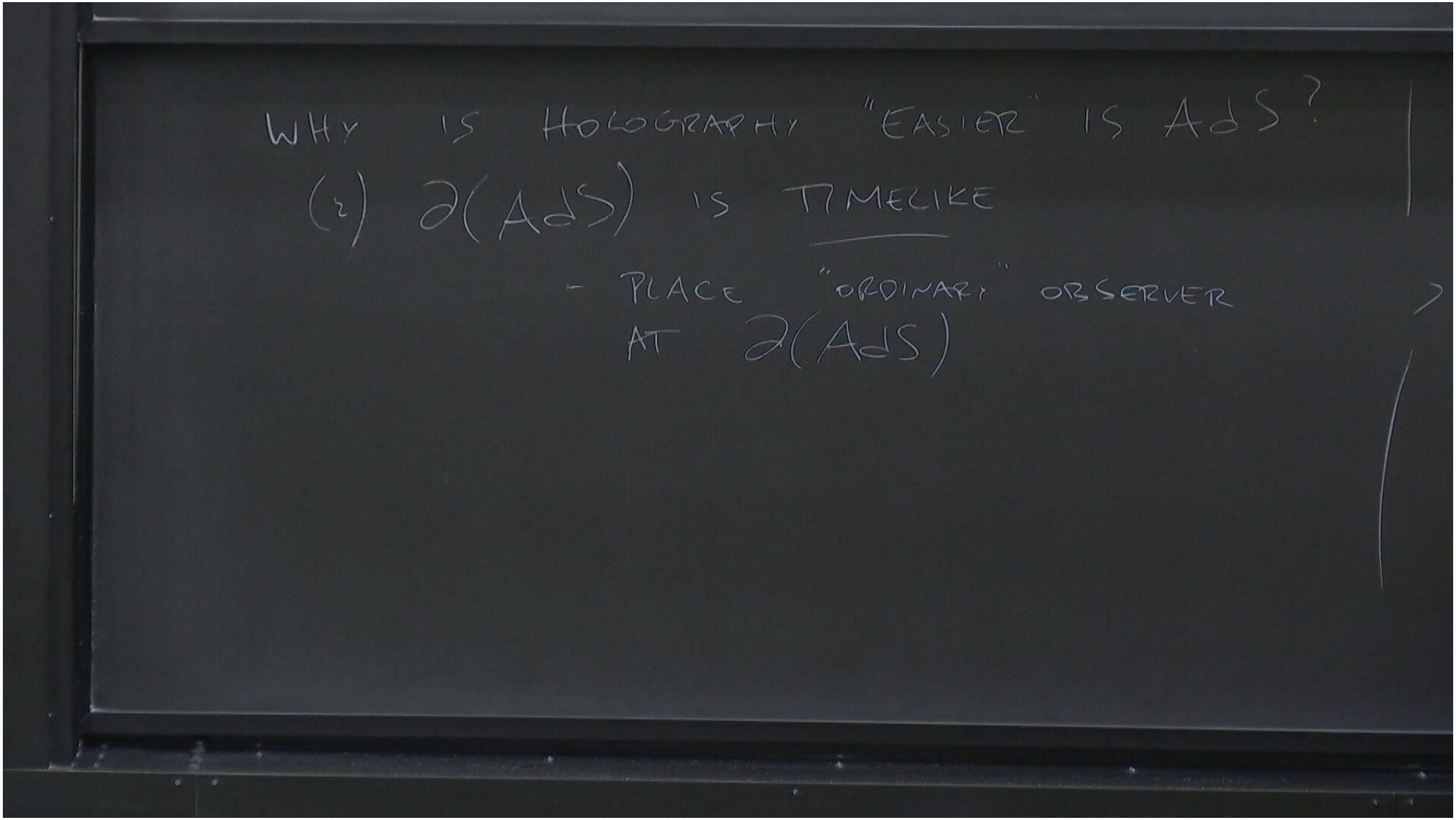
## LECTURE 9 - AdS/CFT

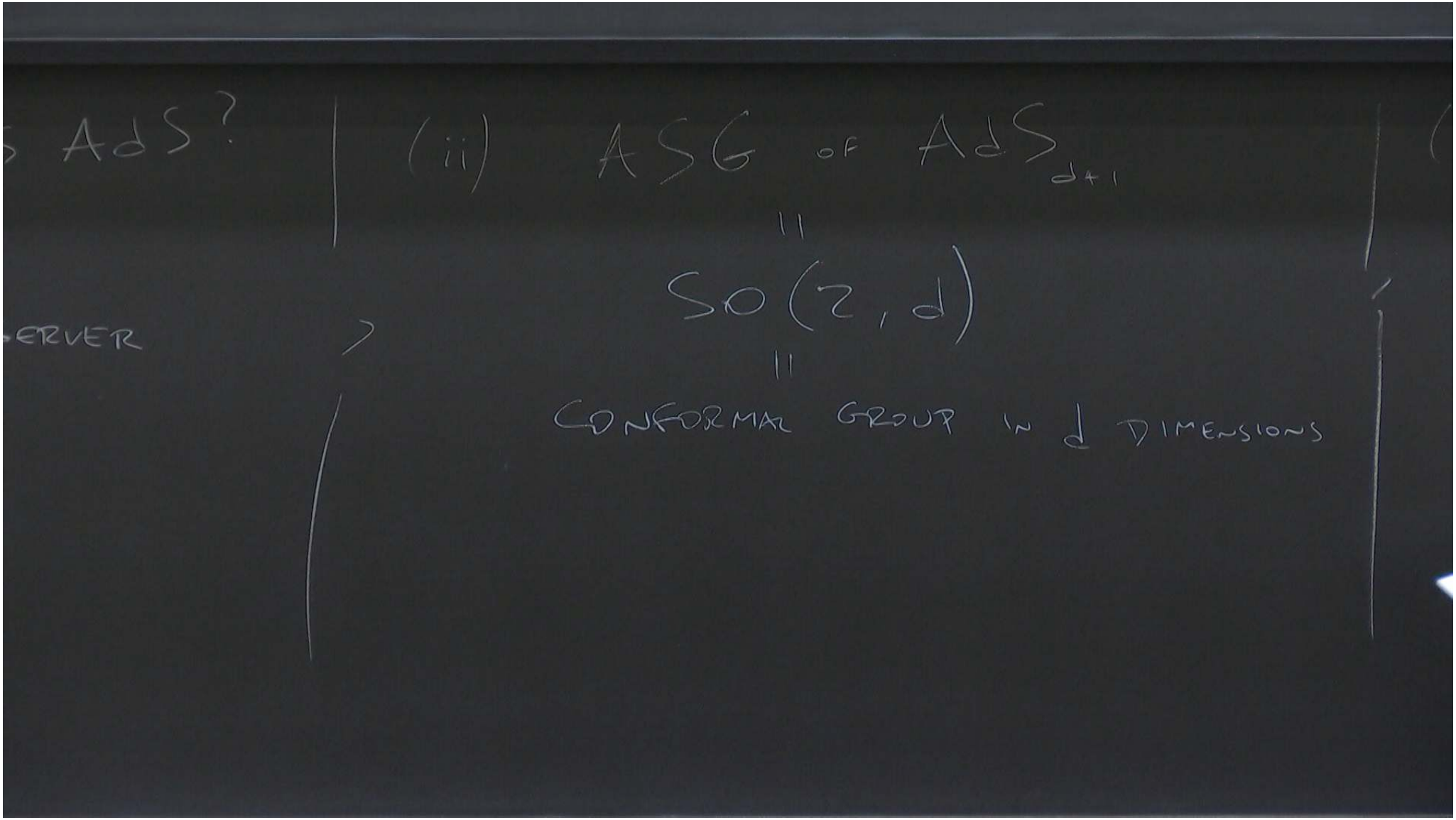
- WHAT IS AdS/CFT?

DUALITY BETWEEN GRAVITY IN $AAdS_{d+1}$ SPACETIMES AND CFT$_d$s IN NONDYNAMICAL SPACETIMES WITH ONE FEWER SPATIAL DIMENSION.


t
$S^{d-1}$
$ds^2_{AdS_{d+1}} = -\left(1+\frac{r^2}{\ell^2}\right)dt^2 + \frac{dr^2}{1+\frac{r^2}{\ell^2}} + r^2 d\Omega^2_{d-1}$
$= \frac{\ell^2}{\cos^2\tau}\left(-dt^2 + d\tau^2 + \sin^2\tau\, d\Omega^2_{d-1}\right)$
$\tan\tau = \frac{r}{\ell}$
(CONFORMAL BDY AT $\tau = \pi/2$)


WHY CARE ABOUT AdS/CFT?
- TOOL FOR STRONGLY COUPLED QFTs
- NONPERT. DEF. OF (SOME THEORY OF) QG (STRING THEORY)
- MOST SOLID FRAMEWORK TO STUDY HOLOGRAPHY

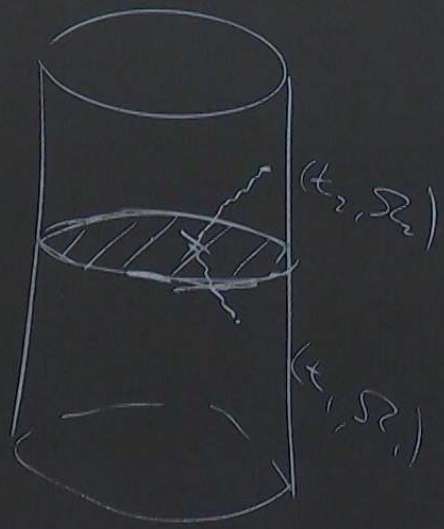

WHY IS HOLOGRAPHY "EASIER" IS AdS?
(2) ∂(AdS) IS TIMELIKE
- PLACE "ORDINARY" OBSERVER AT ∂(AdS)


AdS?
(ii) ASG of $AdS_{d+1}$
=
$SO(2,d)$
=
CONFORMAL GROUP IN d DIMENSIONS

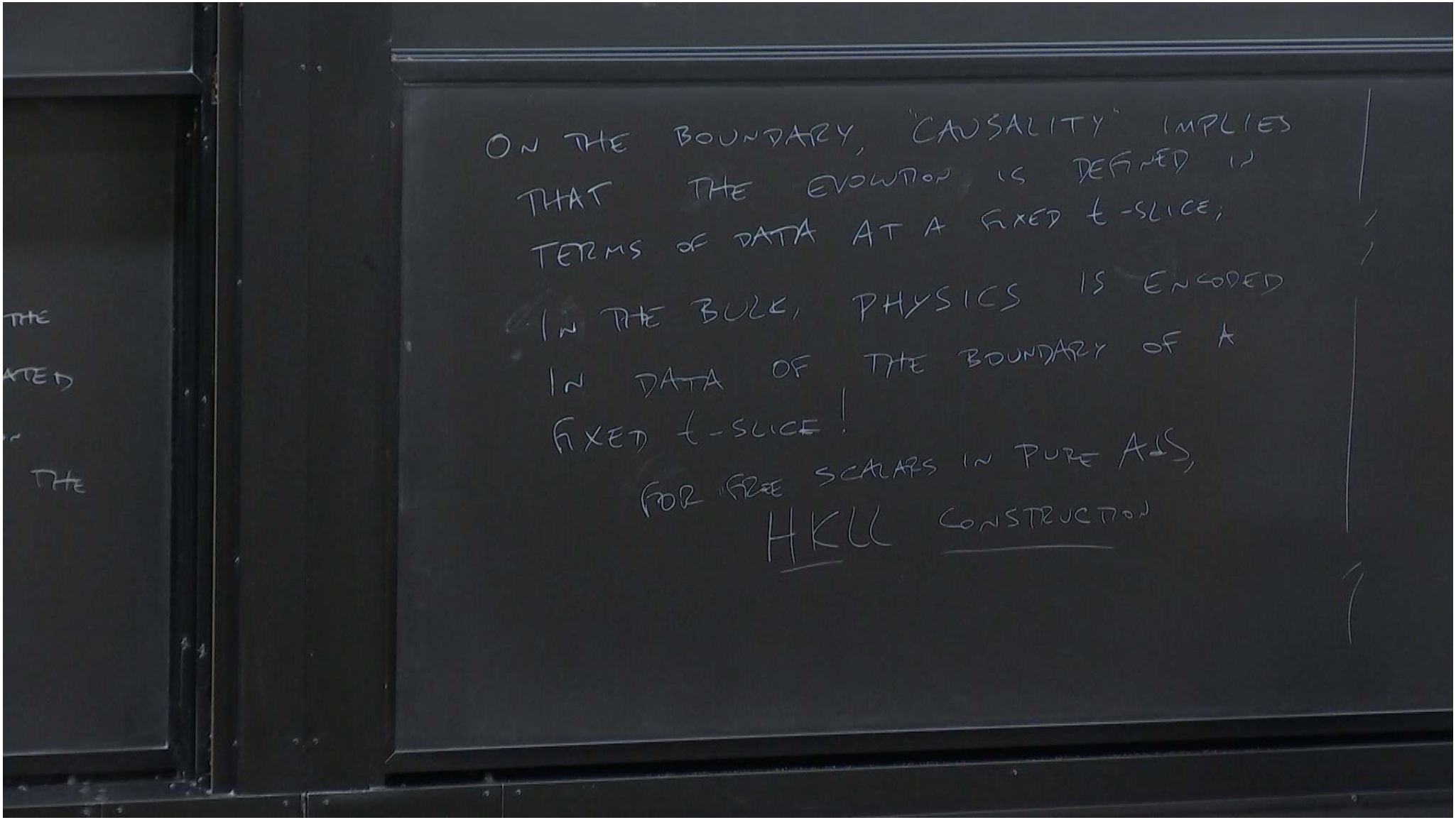
$S_{d+1}$

$d$ DIMENSIONS

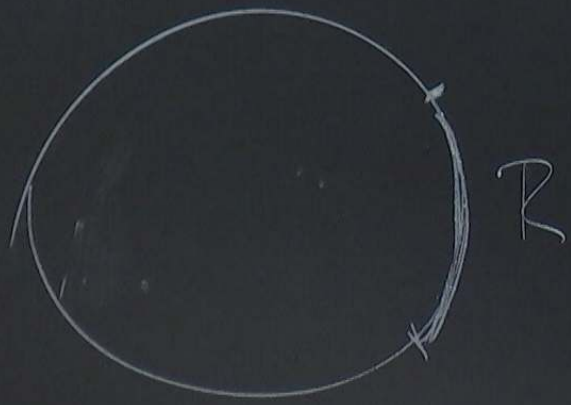
(iii) $AdS_{d+1}$ HAS THE CAUSAL STRUCTURE OF A "BOX"

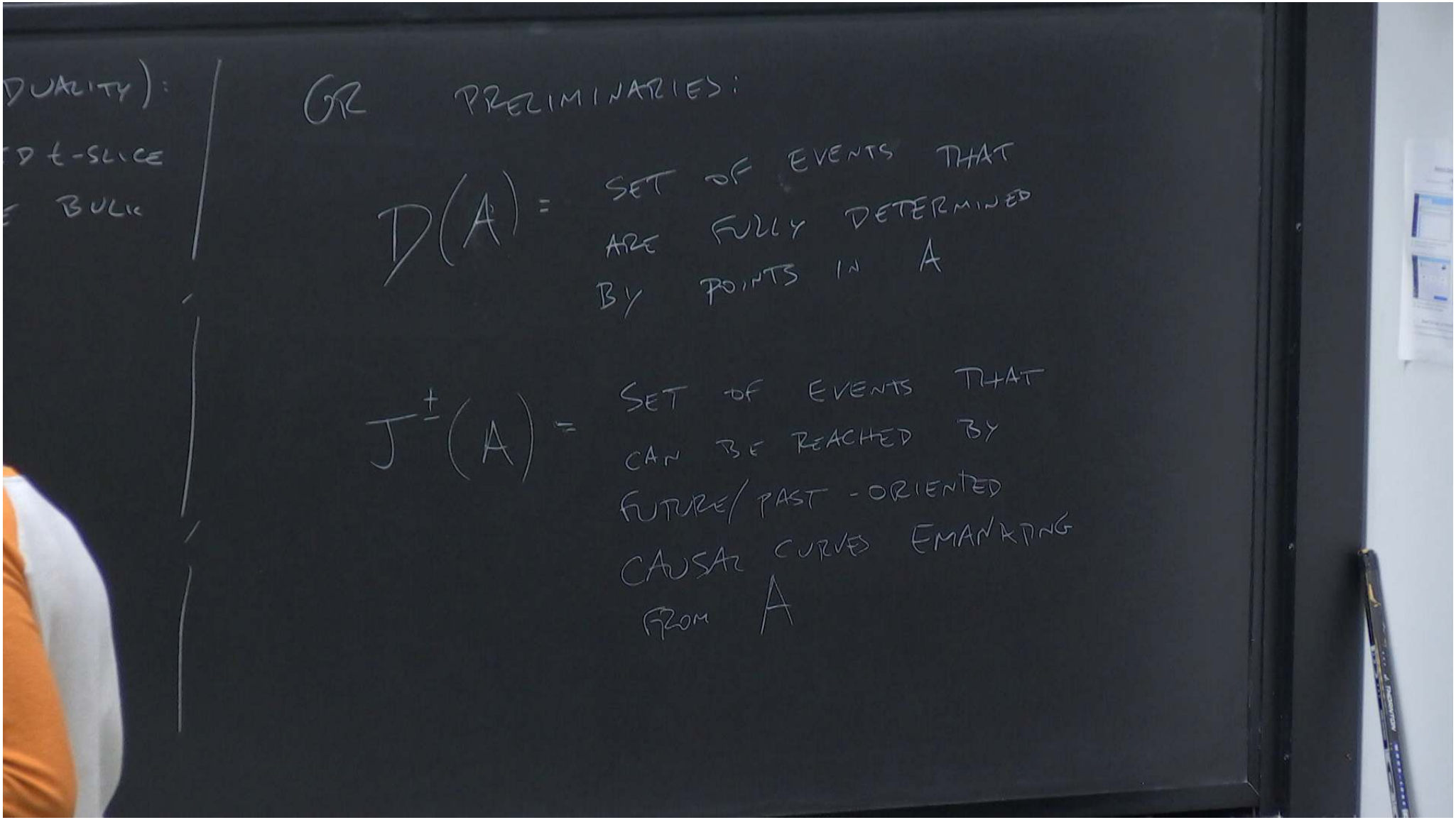


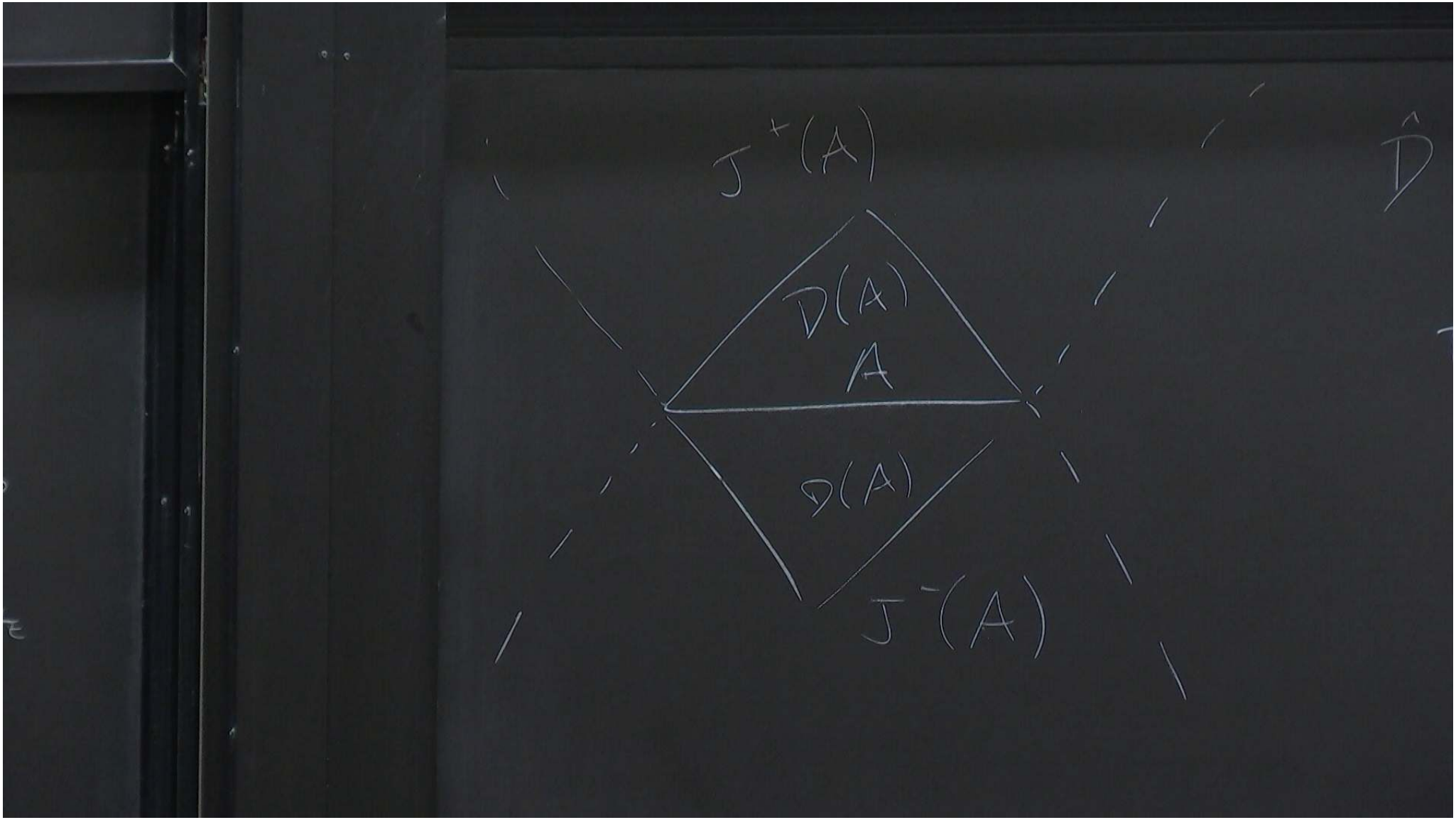

PHYSICS IN THE BULK IS RELATED TO CORRELATION FUNCTIONS ON THE BOUNDARY!


ON THE BOUNDARY, "CAUSALITY" IMPLIES
THAT THE EVOLUTION IS DEFINED IN
TERMS OF DATA AT A FIXED t-SLICE;
IN THE BULK, PHYSICS IS ENCODED
IN DATA OF THE BOUNDARY OF A
FIXED t-SLICE!
FOR FREE SCALARS IN PURE AdS,
HKLL CONSTRUCTION

NATURAL QUESTION: (SUBREGION DUALITY):
GIVEN A SUBREGION $R$ OF A FIXED $t$-SLICE OF THE BOUNDARY, WHAT IS THE BULK SUBREGION?

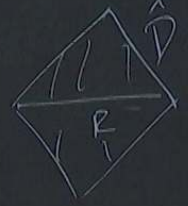


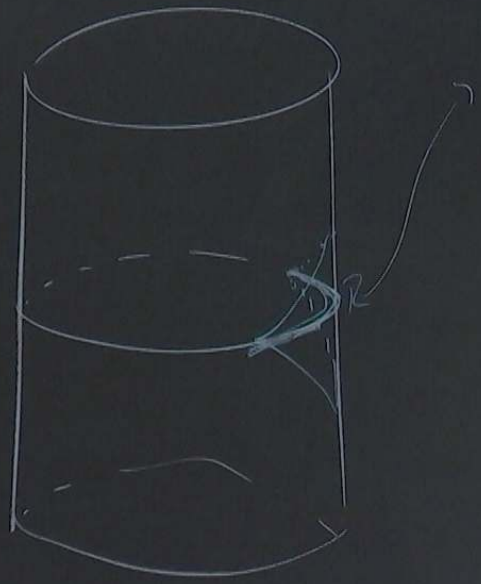

DUALITY):
D t-SLICE
BULK
GR PRELIMINARIES:
D(A) = SET OF EVENTS THAT ARE FULLY DETERMINED BY POINTS IN A
J±(A) = SET OF EVENTS THAT CAN BE REACHED BY FUTURE/PAST-ORIENTED CAUSAL CURVES EMANATING FROM A

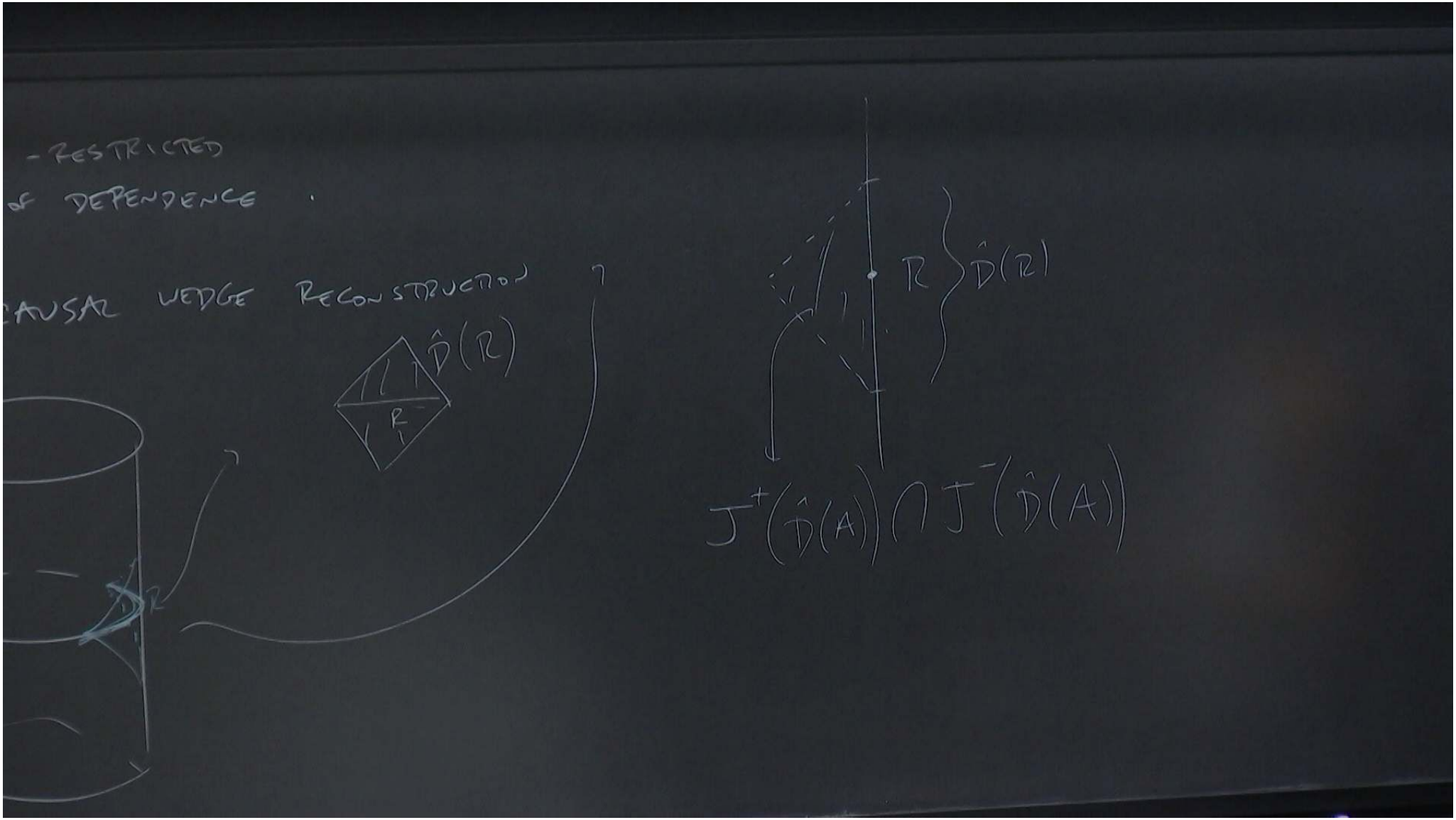

$J^+(A)$
$\hat{D}$
$D(A)$
$A$
$D(A)$
$J^-(A)$

$\hat{D}$ = BOUNDARY-RESTRICTED DOMAIN of DEPENDENCE.

PROPOSAL: CAUSAL WEDGE RECONSTRUCTION

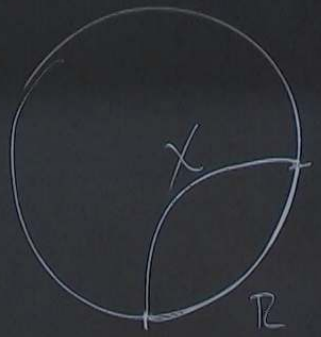



- RESTRICTED
OF DEPENDENCE .
CAUSAL WEDGE RECONSTRUCTION
$\hat{D}(R)$
R
$\hat{D}(R)$
$J^+(\hat{D}(A)) \cap J^-(\hat{D}(A))$

# ENTANGLEMENT WEDGE RECONSTRUCTION:

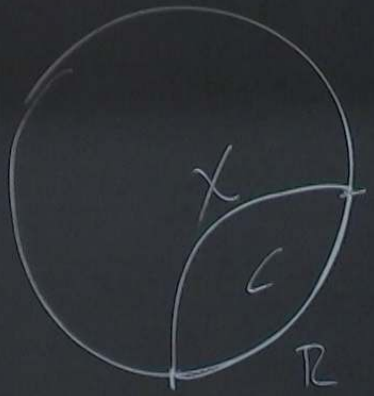
↳ ENTANGLEMENT IN THE BOUNDARY THEORY BUILDS GEOMETRY IN THE BULK!




(RT)

- RYU-TAKAYANAGI FORMULA: (STATIC CASE)

$$S(R) = \min_{\chi} \frac{A(\chi)}{4G_N}$$




HRT FORMULA.

$$S(R) = \min_{\chi} \operatorname{ext}\left( \overbrace{\frac{A(\chi)}{4G_N} + S_{\text{BULK}}(C)}^{S_{\text{Gen}}(\chi)} \right),$$

RECIPE:

FIND THE QES $\chi_R$ THAT EXTREMIZES $S_{\text{gen}}(\chi)$;

TAKE $C_R$ SUCH THAT $\partial C_R = \chi_R \cup R$;

TAKE $\mathcal{E}(R) \equiv \mathcal{D}(C_R)$.

STATEMENT:

THE BOUNDARY SUBREGION $R$

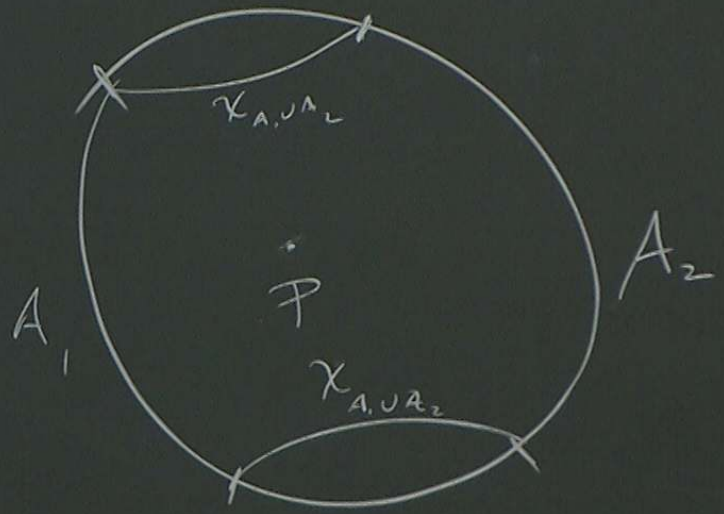
ENCODES THE PHYSICS IN

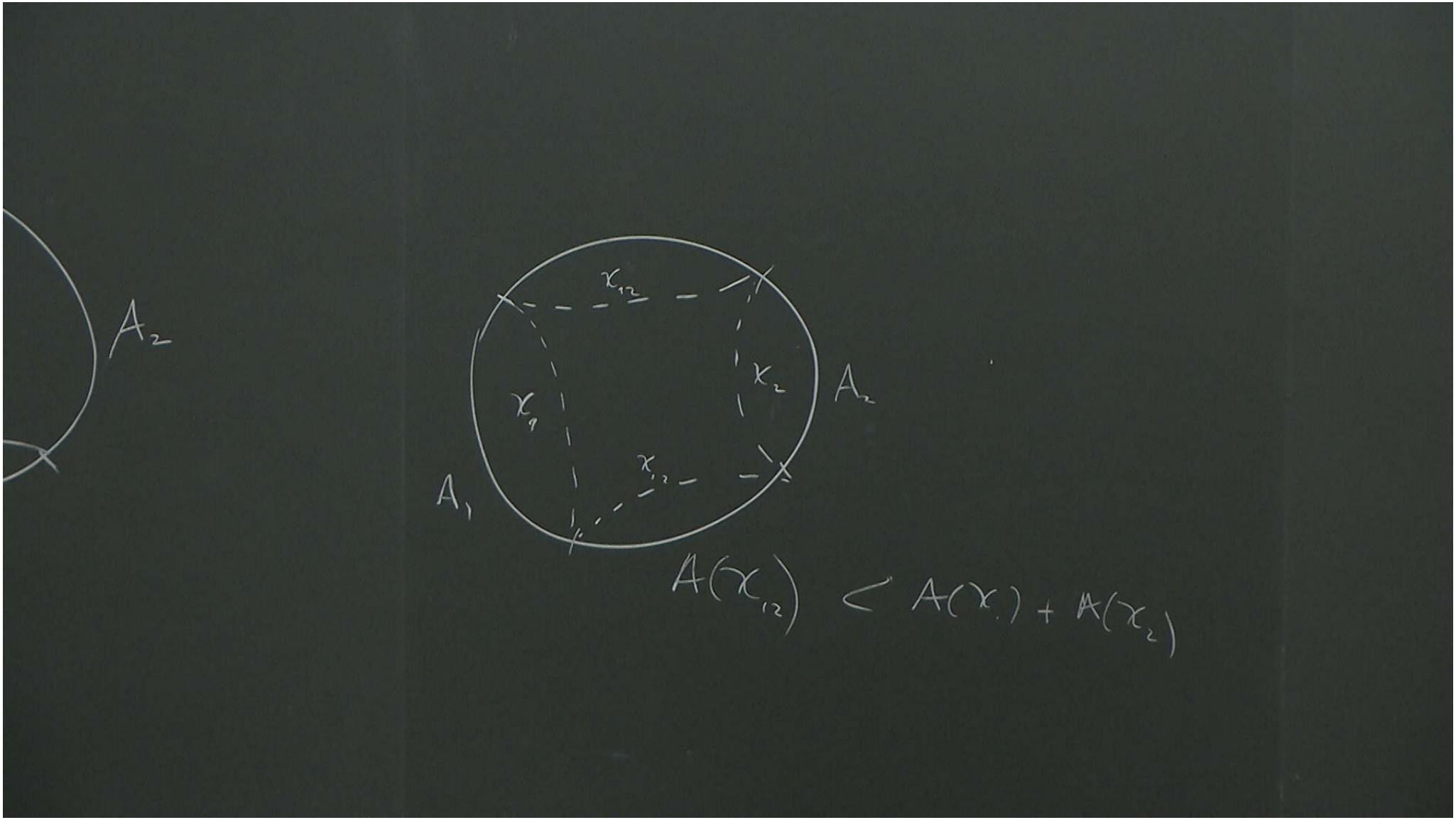
$\mathcal{E}(R)$.

HE BOUNDARY SUBREGION $R$

NCODES THE PHYSICS IN

$\mathcal{E}(R)$.




$A_2$
$\chi_{12}$
$\chi_2$
$\chi_1$
$\chi_3$
$A_2$
$A_1$
$A(\chi_{12}) \leq A(\chi_1) + A(\chi_2)$