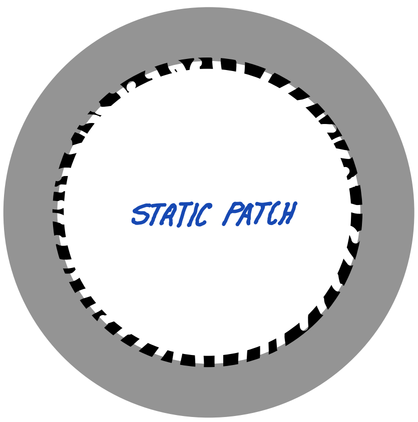
DE SITTER SPACE AND THE HOLOGRAPHIC PRINCIPLE



$N \sim \frac{\text{AREA}}{4G}$

WHAT ARE THE HOLOGRAPHIC DOF, THEIR DYNAMICS, AND THE DICTIONARY?

WE NEED CONCRETE EXAMPLES.

DSSYK$_\infty$

DOUBLE-SCALED SYK AT ∞ TEMP

1. CONJECTURE: ?

DSSYK$_\infty$ DUAL TO DE SITTER SPACE.

L.S. arXiv:2209.09999

H. VERLINDE UNPUBLISHED

2. DSSYK$_\infty$ HAS SIMILAR FEATURES TO LARGE-N QCD.

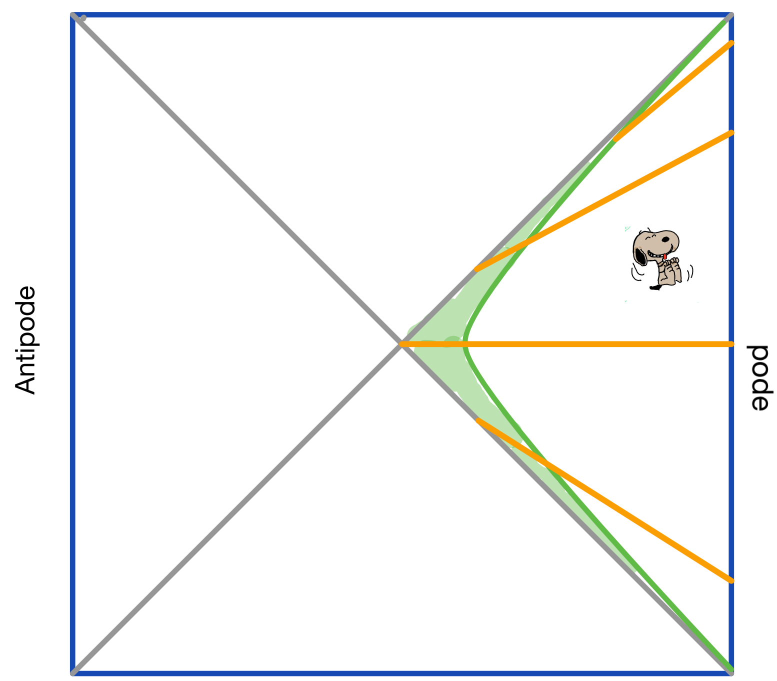
CONFINEMENT

ALMOST EVERYTING IS CONFINED IN DE SITTER SPACE.

FRAMEWORK

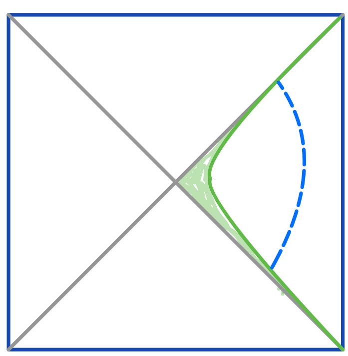
STATIC PATCH HOLOGRAPHY

HOLOGRAPHIC DOF LOCALIZED
ON STRETCHED HORIZON.

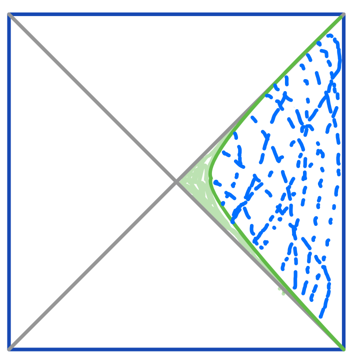


A PUZZLE:

DSSYK$_\infty$ HAS N SPECIES OF MASSLESS FERMIONS χ_i. IF ALL OF THESE CAN ESCAPE (AS GIBBONS-HAWKING RADIATION)



THERE WOULD BE FAR TOO MANY QUANTA IN THE STATIC PATCH.



WHAT IS THE HOLOGRAPHIC MECHANISM THAT KEEPS THEM FROM ESCAPING THE HORIZON ?

CONFINEMENT

(SIMILAR TO QUARK CONFINEMENT)

THE GRAVITY SIDE OF THE DUALITY

$$DS(2+1) \xrightarrow[\text{DIM-REDUCT}]{} JT - DE \text{ SITTER}$$

$$ds^2 = -\left(1-\frac{r^2}{L_c^2}\right)dt^2 + \frac{dr^2}{\left(1-\frac{r^2}{L_c^2}\right)} + r^2 d\alpha^2$$

$$\xrightarrow[\text{DIM-REDUCT}]{}$$

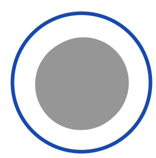
$$\boxed{\begin{aligned} ds^2 &= -\left(1-\frac{r^2}{L_c^2}\right)dt^2 + \frac{dr^2}{\left(1-\frac{r^2}{L_c^2}\right)} \\ \Phi &= r \end{aligned}}$$

MASS AND LENGTH SCALES IN

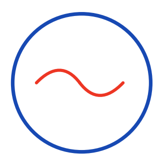
THE DE SITTER <u>SEMICLASSICAL</u> LIMIT.

START WITH $D=4$

$$M_{max} = \frac{L_c}{G_4}$$



$$M_{min} = \frac{\hbar}{L_c} = T_{GH}$$



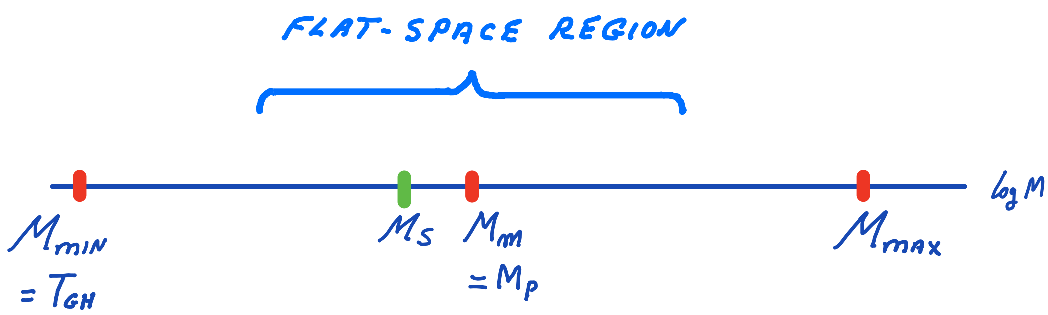
$$M_m = \sqrt{M_{max} M_{min}} = \left(\frac{\hbar}{G_4}\right)^{1/2} = M_{PLANCK}$$

m = MEAN,

MIDDLE, MICRO

ONE MORE IMPORTANT SCALE

$$M_{STRING} = g\, M_{PLANCK}$$



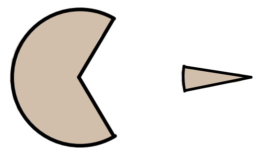
$$L_c = \frac{\hbar}{M_{MIN}}$$

$$L_m = \frac{\hbar}{M_m} = L_p$$

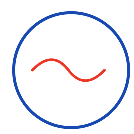
$$L_s = \frac{\hbar}{M_s}$$

$$D = 3$$

$$M_{max} = \frac{1}{G_3} = M_{PLANCK}$$



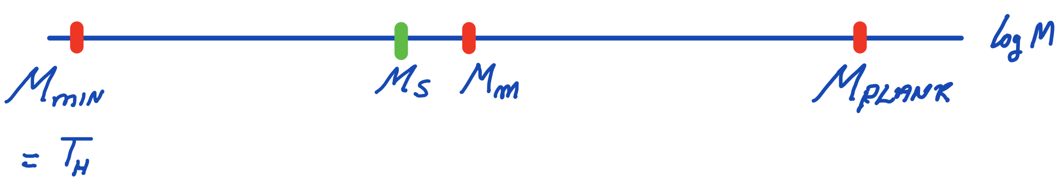
$$M_{MIN} = T_{GH} = \frac{\hbar}{L_c}$$



$$M_m = \sqrt{\frac{\hbar}{G_3 L_c}}$$

m = MEAN, MIDDLE, MICRO

$$\boxed{\left(\frac{M_S}{M_m}\right)^2 = \lambda = \text{FINITE}}$$



DSSYK$_\infty$

$$H = i^{q/2} \sum_{i_1 < i_2 \cdots < i_q} J_{i_1 \ldots i_q} \, x_{i_1} \cdots x_{i_q}$$

$$\{x_a, x_b\} = 2\,\delta_{ab}$$

$$\langle J^2 \rangle = \frac{q!}{N^{q-1}} \, \mathcal{J}^2 \qquad (H_c = H_s\, q)$$

$$N \to \infty$$

$$\boxed{\frac{q^2}{N} = \lambda \qquad T = \infty}$$

$$\boxed{\left(\frac{M_s}{M_m}\right)^2 = \lambda = \text{FINITE}}$$

CLPW 2206.10780 [hep-th]

LIN SUSS 2206.01083 [hep-th]

DICTIONARY

$$M_{MIN} = J \quad *$$

$$M_{MAX} = JN$$

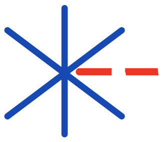
$$M_m = J\sqrt{N}$$

$$M_s = gJ \quad ??$$

$$\boxed{\left(\frac{M_s}{M_m}\right)^2 = \frac{g^2}{N} = \lambda}$$

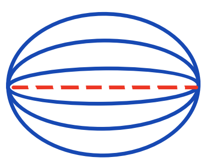
WE WILL RETURN TO M_s

PERTURBATION THEORY



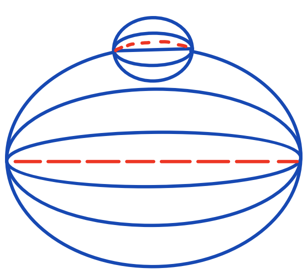
t_2 $\qquad$ t_1 $\quad = \epsilon(t_2 - t_1)$

$$= J^2 \frac{q!}{N^{q-1}}$$

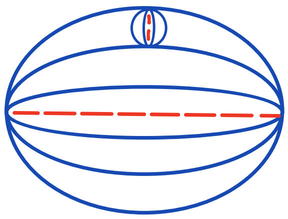


$$= \frac{N^q}{q!} \times J^2 \frac{q!}{N^{q-1}} \times \int dt$$

$$= \left(J^2 \int dt\right) N$$

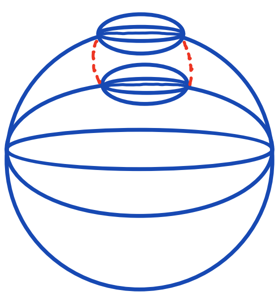


$$= \left(J^4 \int d^3t \;\; q^2\right) N$$



$$= \left(\mathcal{J}^4 \int d^3 t \;\; g^4 \right)$$

DOWN BY N



$$\sim \mathcal{J}^6 \lambda^2 N^4 \sqrt{\frac{\lambda}{N}}^{\,\sqrt{\lambda N}} \int d^5 t$$

WAY DOWN

NPC

$$N^{-a}\,\text{AMPLITUDE} = \sum_{n=0}^{\infty} \frac{P_n(g)}{N^n} + NPC$$

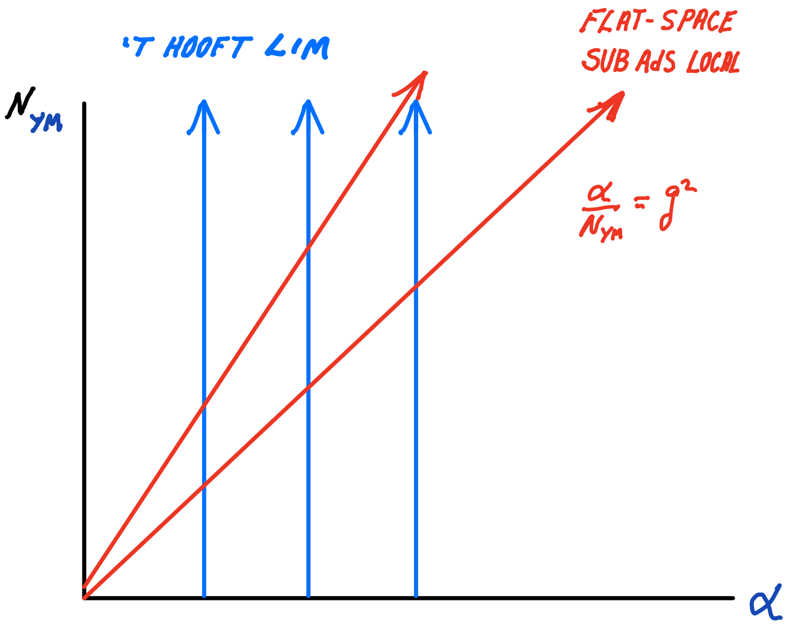
COMPARE WITH 'T HOOFT EXPANSION

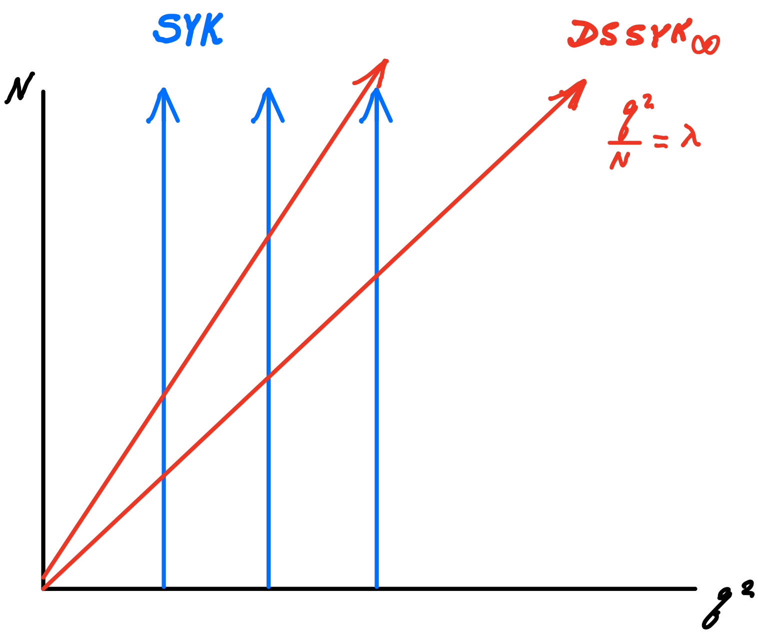
$$\sum_{n=0}^{\infty} \frac{P_n(\alpha)}{N^n} + NPC \qquad \begin{cases} N = N_{YM}^2 \\ \alpha = \text{'T HOOFT COUPLING} \end{cases}$$

DSSYK $\qquad \dfrac{g^2}{N} = \lambda$

LARGE N QCD $\qquad \dfrac{\alpha}{N_{YM}} = g_{YM}^2$

$$\boxed{\begin{array}{c} g^2 \longleftrightarrow \alpha \\ \lambda \longleftrightarrow g_{YM}^2 \end{array}}$$

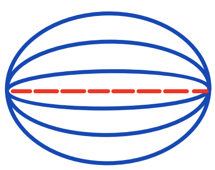

'T HOOFT LIM
FLAT-SPACE
SUB AdS LOCAL
N_{YM}
$\frac{\alpha}{N_{YM}} = g^2$
α

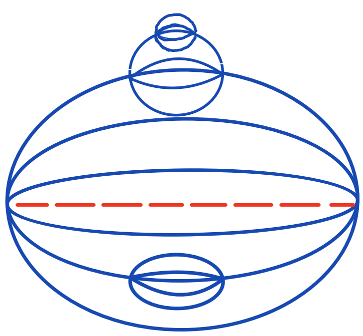

SYK
$DSSYK_\infty$
N
$\frac{g^2}{N} = \lambda$
g^2

String (Confinement) Scale

Visible in QCD "planar" sum

Visible in DKSYK$_\infty$ melon sum

 $= \int dt$ (IR divergent)

 $= \int \frac{dt}{\cosh^2 gJt} \sim \frac{1}{gJ}$

Maldacena Stanford

Roberts Stanford Streicher

Qi Streicher

$$\boxed{M_s = \frac{1}{L_s} = gJ}$$

$$M_m \approx J\sqrt{N}$$

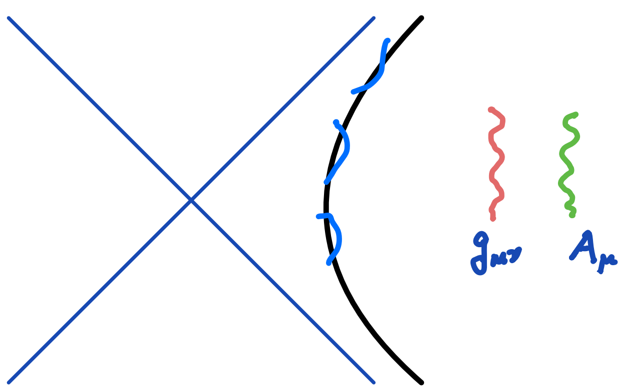
$$M_s \approx gJ$$

$$\boxed{\left(\frac{M_s}{M_m}\right)^2 \approx \frac{g^2}{N} \approx \lambda}$$

LOCALITY

CONFINEMENT

TOO MANY DOF x_i UNLESS MOST ARE CONFINED.



NO GRAVITONS IN (2+1)

PHOTONS ?

COMPLEX SYK χ_i , $\bar{\chi}_i$

SYMMETRY

$U(1)$ $$\chi_i \to e^{i\theta}\chi_i$$
$$\bar{\chi}_i \to e^{-i\theta}\bar{\chi}_i$$

BULK MAXWELL THEORY - PHOTONS

$SU(N)$ "ENSEMBLE-SYMMETRY"
(NOT A "REAL" SYMMETRY)

$$\chi_i' = U_{ij}\,\chi_j$$

$$\boxed{\text{THE CONFINED CHARGES ARE } SU(N)}$$

$\bar{x}\ x$ PAIR

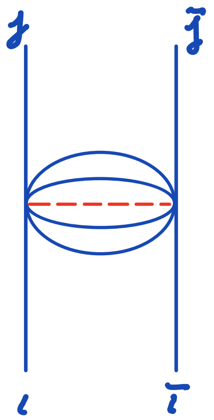
SINGLET

$$\sum_i \bar{x}_i\, x_i$$

ADJOINT

$$\sum_{ij} t_{ij}\, \bar{x}_i\, x_j \qquad Tr\, t_{ij} = 0$$

$$E = 2\epsilon_x + V$$



$$V = -\frac{N^{q-2}}{(q-2)!} \times J^2 \frac{q!}{N^{q-1}} \times \frac{1}{qJ} \times \mathcal{M}$$

$$= -\frac{qJ}{N} \mathcal{M}$$

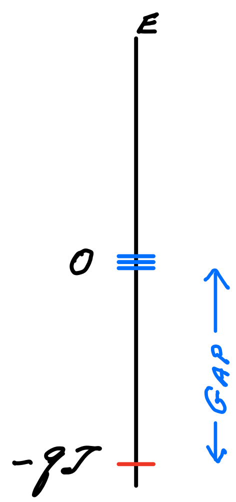
$$\begin{pmatrix} 1 & \bar{1} \\ 2 & \bar{2} \\ 3 & \bar{3} \\ & \vdots \\ N & \bar{N} \end{pmatrix} \qquad \mathcal{M} = \begin{pmatrix} 1 & 1 & 1 & 1 & \cdots & 1 \\ 1 & 1 & 1 & 1 & \cdots & 1 \\ 1 & 1 & 1 & 1 & \cdots & 1 \\ 1 & 1 & 1 & 1 & \cdots & 1 \\ \vdots & \vdots & \vdots & \vdots & \ddots & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 \end{pmatrix}$$

$$\mathcal{M} = N \, \mathbb{P}_{SINGLET}$$

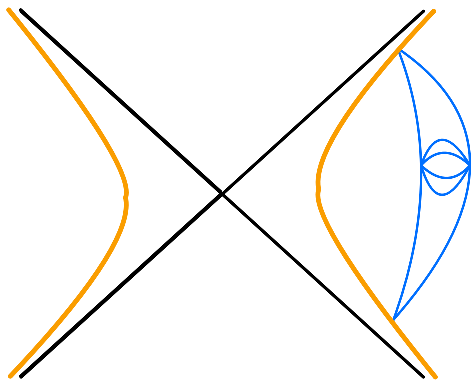
$$\Lambda(M) = N \qquad \text{SINGLET}$$

$$\Lambda(M) = 0 \qquad \text{ADJOINT}$$

$$V = \begin{cases} -gJ & \text{SINGLET} \\ 0 & \text{ADJOINT} \end{cases}$$



SOMETHING'S WRONG



$$\left\langle \sum_i \bar{\chi}_i \chi_i(0) \sum_j \bar{\chi}_j \chi_j(t) \right\rangle$$

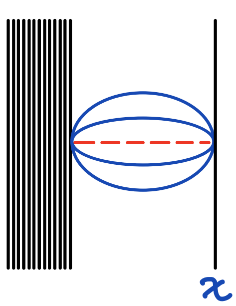
$\sim e^{iEt}$

$\sim e^{-iq\mathcal{J}t}$ SINGLET

BUT $\sum_i \bar{\chi}_i \chi_i = Q$ = CONSERVED $U(1)$ CHARGE

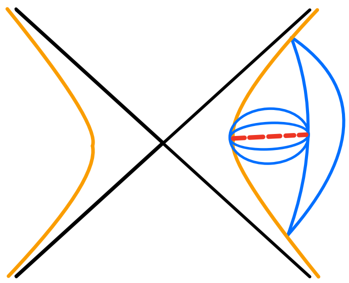
THEREFORE $E_{\text{SINGLET}} = 0$

SINGLE FERMION ENERGY? $E = 2\epsilon_\chi + V$



$$N \times \frac{N^{q-2}}{(q-2)!} \times \mathcal{J}^2 \frac{q!}{N^{q-1}} \times \frac{1}{q\mathcal{J}}$$

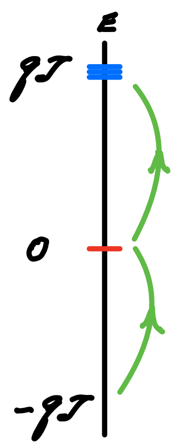
$$\sim \mathcal{J}q = \epsilon_\chi$$



$$E = -qJ + 2\epsilon_x \qquad \text{SINGLET}$$

$$2\epsilon_x \qquad \text{ADJOINT}$$

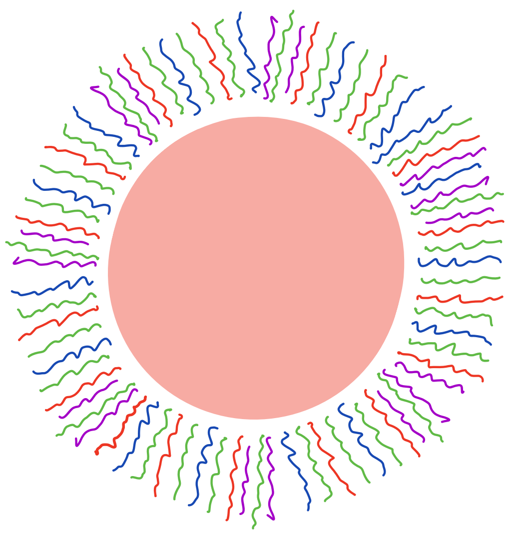
$$E_{SING} = 0 \quad \text{IF} \quad \epsilon_x = \frac{qJ}{2}$$



$$\boxed{\begin{aligned} E_{SING} &= 0 \\ E_{ADJOINT} &= qJ \\ \epsilon_x &= \frac{qJ}{2} \end{aligned}}$$

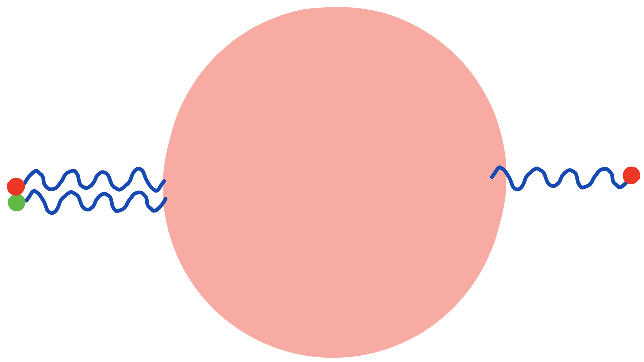
LARGE–N
QCD-PLASMA ANALOG

PLASMA
BUBBLE

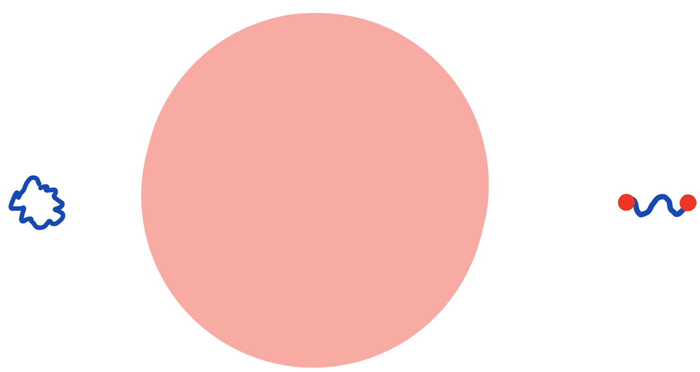


VERY RAPID EVAPORATION

LUMINOSITY $\sim N = N_{YM}^2$



NON - SINGLET



SINGLET

THERE ARE VERY FEW SINGLETS

EVAPORATION SLOW.

INDEPENDENT OF N

IN DSSYK$_\infty$ IT IS THE "FAKE" ENSEMBLE-SYMMETRY CHARGES THAT ARE CONFINED.

IN D=4 THE HOLOGRAPHIC DOF ARE MATRICES

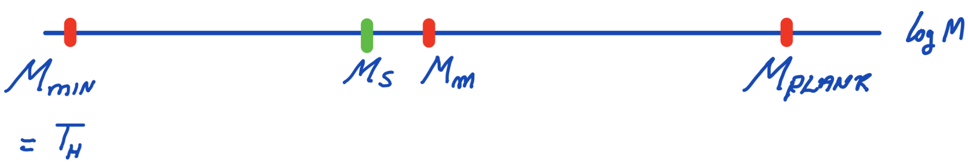
BANKS, FIOL, MORISSE hep-th/0609062

L.S. 2109.01322 [hep-th]

WITH "TRUE" SU(N) SYMMETRY.

REVIEW

1. SEPARATION OF SCALES IN SEMICLASSICAL LIMIT.



2. EMERGENT STRING SCALE

$$M_s = gJ$$

$$\left(\frac{M_s}{M_m}\right)^2 = \lambda = \frac{g^2}{N}$$

3. CONFINEMENT OF SU(N) CHARGE. ALMOST ALL DOF ARE CONFINED TO VICINITY OF THE STRETCHED HORIZON.

4. SUB dS LOCALITY *

$$\frac{L_s}{L_c} = \frac{1}{g} \longrightarrow 0$$

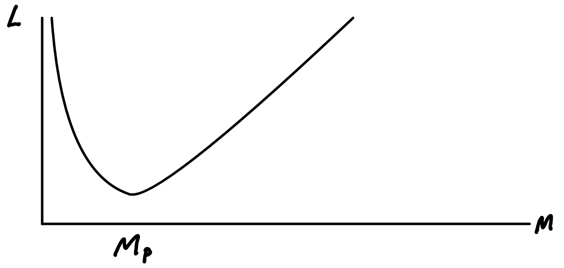
*CHORDS

BERKOOZ, BRUKNER, NAROVLANSKY, RAZ

LIN

Length Scales

4D: $L(M) = \frac{\hbar}{M} + MG$



3D: $L = \frac{\hbar}{M} + L_c \frac{M}{M_p}$