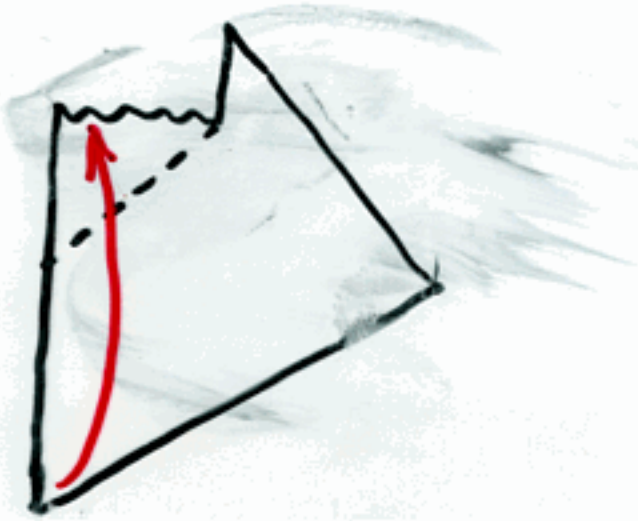
QUANTUM GRAVITY IN THE BAD OLD DAYS

$$Z = \int dg_{\mu\nu} \exp i \int \sqrt{g}\, R$$

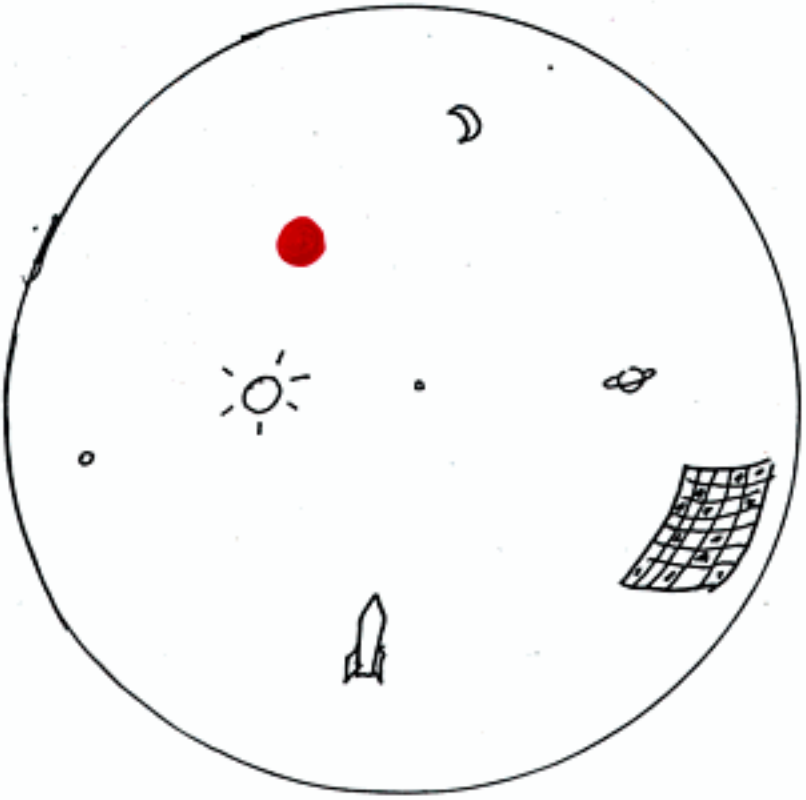
DIVERGENCES

TOPOLOGY CHANGE



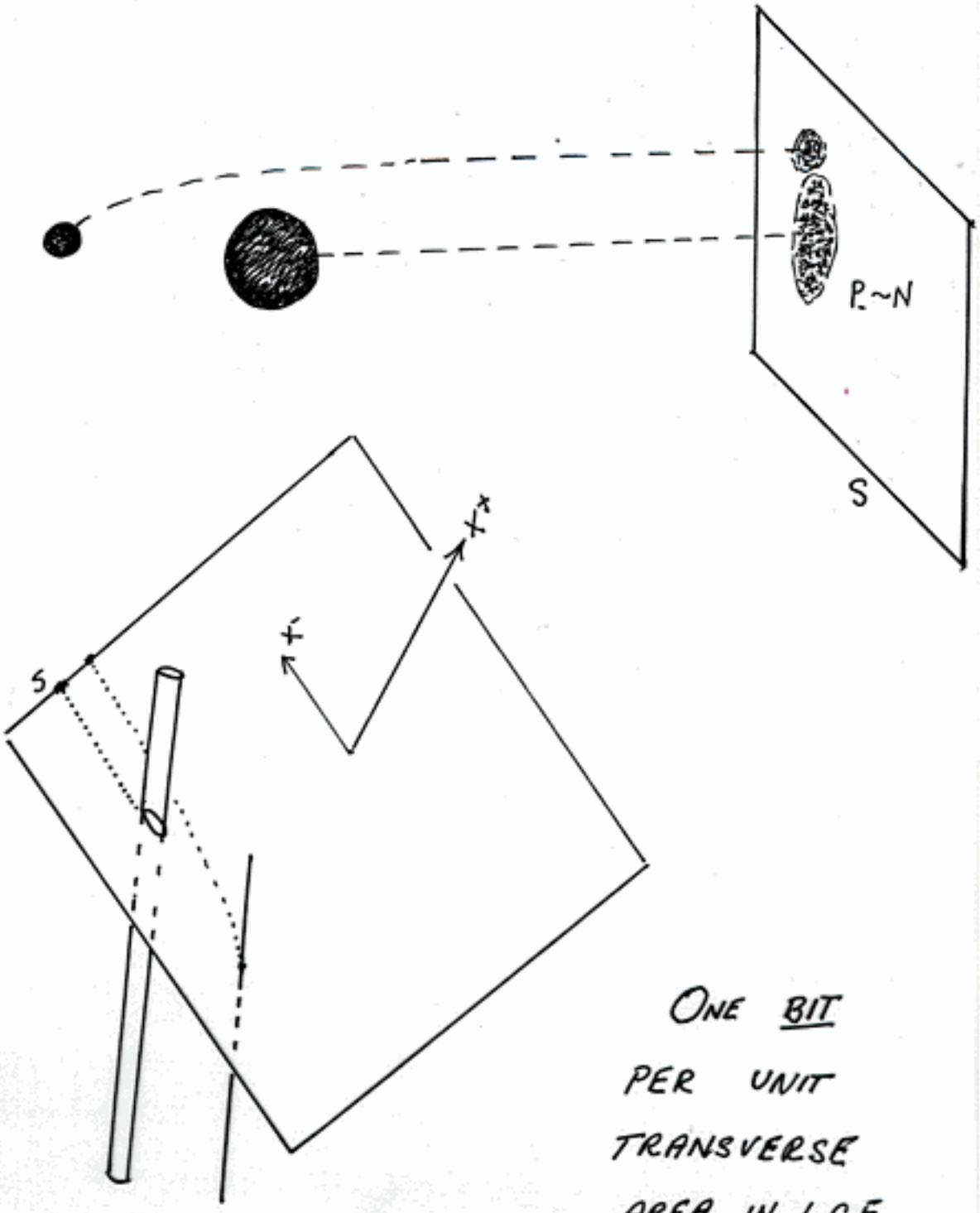
INFORMATION LOSS

THE HOLOGRAPHIC PRINCIPLE



$$S_{MAX} = \frac{\text{AREA}}{4G\hbar} \neq \text{VOLUME}$$

$$\text{NUMBER OF D.O.F.} \approx S_{MAX}$$

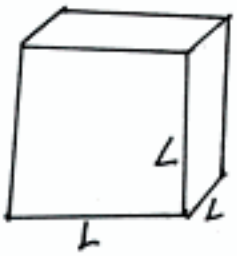


ONE <u>BIT</u>
PER UNIT
TRANSVERSE
AREA IN L.C.F.

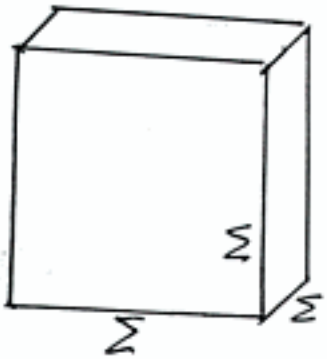
MATRIX THEORY (SYM) = DLCQ of M-T

HOLOGRAPHY MUST BE A PROPERTY OF SYM.

3-TORUS



M-THEORY TORUS



SYM TORUS

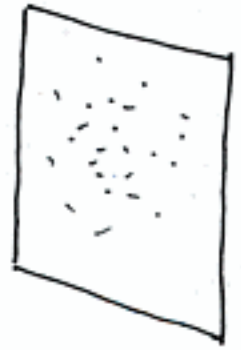
$$S = N^2 \Sigma^3 T^3$$

$$\langle X^2 \rangle = \frac{\ell_{11}^3}{L} N \Sigma^2 T^2 = G_8^{1/3} N \Sigma^2 T^2$$

$$\text{AREA} = \langle X^6 \rangle = G_8 N^3 \Sigma^6 T^6$$

$$G_8 \frac{S}{A} = \frac{1}{T^3 \Sigma^3 N}$$

$$\frac{G_g S}{A} = \frac{1}{T^3 \Sigma^3 N}$$



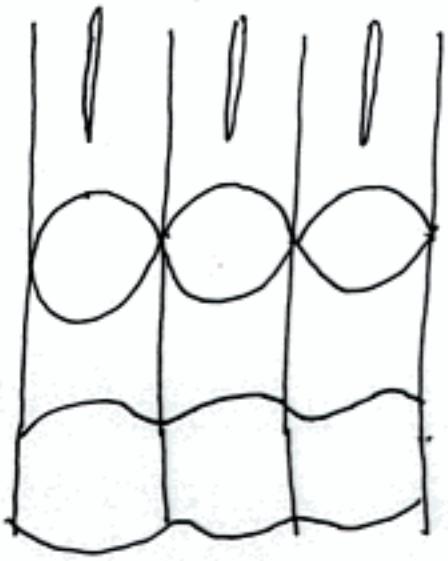
HIGH T

RECALL $\Sigma_{EFF} \sim N^{1/3} \Sigma$

LOW T

$$T_{CRIT} = \frac{1}{\Sigma N^{1/3}}$$

PHASE TRANSITION AT $\frac{G_g S}{A} \approx 1$



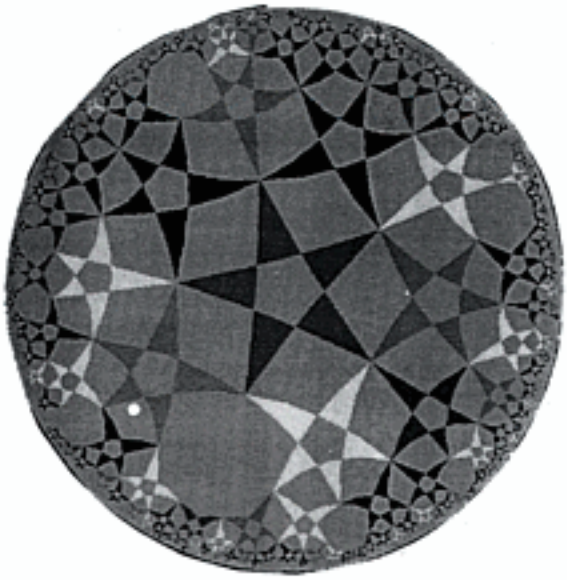
$N \gg S$

$N \sim S$ $\quad T = T_{CRIT}$

$N < S$

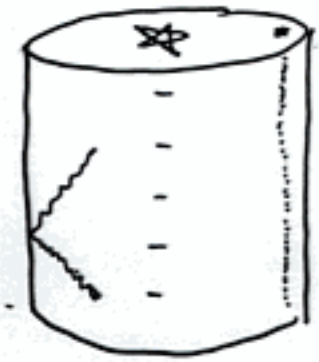

GS/A
1
T^{-1}
BLACK STRING
T_{CRIT}^{-1}
SCHWARZSCHILD BH

THE CASE OF $AdS_5 \times S_5$



A SPATIAL SECTION OF AdS

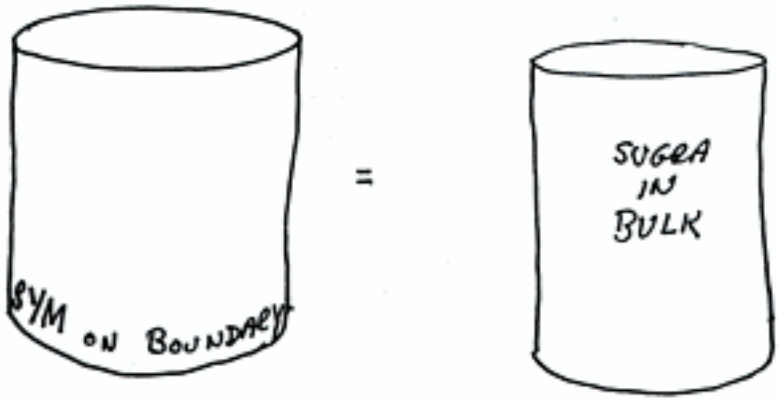
$$dS^2 = R^2 \left[\frac{4\, dx^i dx^i}{(1-r^2)^2} - \frac{(1+r^2)^2}{(1-r^2)^2} dt^2 \right]$$



SUPERGRAVITY/IIb STRING THEORY IN $AdS_5 \times S_5$

IS EQUIVALENT TO 3+1 DIM SUPER YANG MILL

ON THE BOUNDARY $(S_3 \times R) \times S_5$



SEE
MALDACENA
WITTEN
KLEBANO GUBSER
⋮

$$\left(g_{YM}^2 N\right)^{1/4} l_s = R$$ (RADIUS OF $AdS \times S_5$)

IN SOME SENSE HOLOGRAPHIC BUT
IN WHAT SENSE IS THE NUMBER OF
D.O.F. = TO 1 PER PLANCK AREA ?

NUMBER OF S.Y.M DEGREES OF FREEDOM IS ∞ FOR 2 REASONS

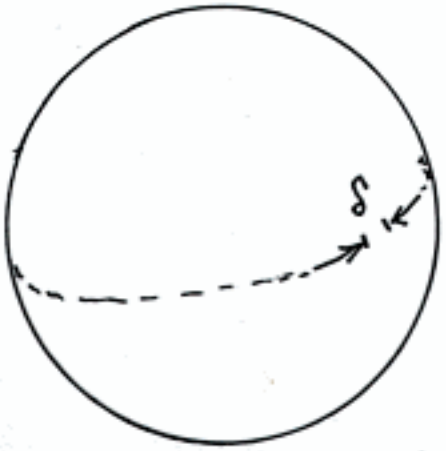
1 CONTINUUM QFT

2 $N \to \infty$

THATS OK BECAUSE BONDARY SPHERE HAS ∞ AREA.

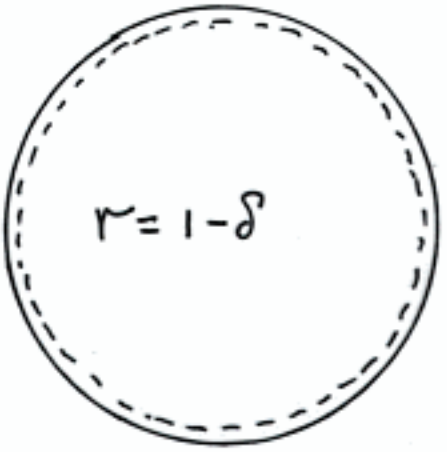
CAN WE REGULATE THESE ∞'s ?

<u>THE</u> <u>U.V.</u>, <u>I.R.</u> <u>CONNECTION</u> L.S. E.W.



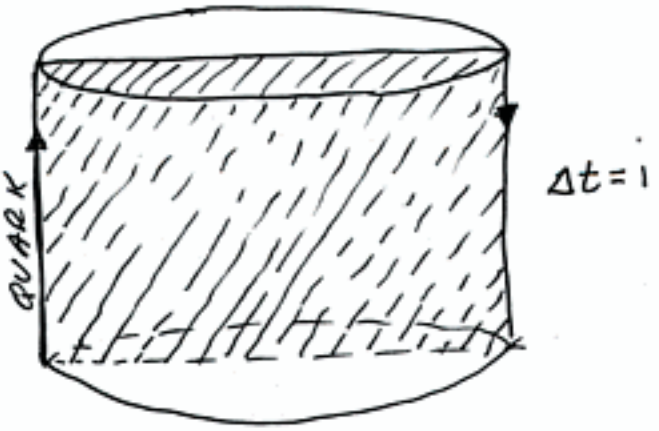
SYM (RADIUS = 1)

REGULATOR LENGTH $= \delta$



SUGRA/STRING

AN EXAMPLE OF UV, IR



$$\text{AREA} = \Delta t \int \sqrt{g_{00} g_{rr}} \, dr$$

$$\text{ENERGY} = \int \sqrt{g_{00} g_{rr}} \, dr = \int \frac{1+r^2}{(1-r^2)^2} \, dr \times R^{4}$$

THIS IS LINEARLY DIVERGENT AT $r=1$

IT REFLECTS THE ∞ U.V. ENERGY OF A <u>POINT</u> CHARGE.

INTEGRATING TO $r = 1-\delta$ GIVES

$$\text{ENERGY} \sim \frac{1}{\delta}$$ AS WOULD BE

EXPECTED FROM U.V. CUTOFF.

Now Count

$$N_{DOF} = \frac{N^2}{\delta^3}$$ SYM SIDE

$$\text{Area of AdS Boundary} = \frac{R^3}{\delta^3}$$ GRAVITY SIDE

$$N_{DOF} = \frac{N^2}{R^3} \text{Area}$$

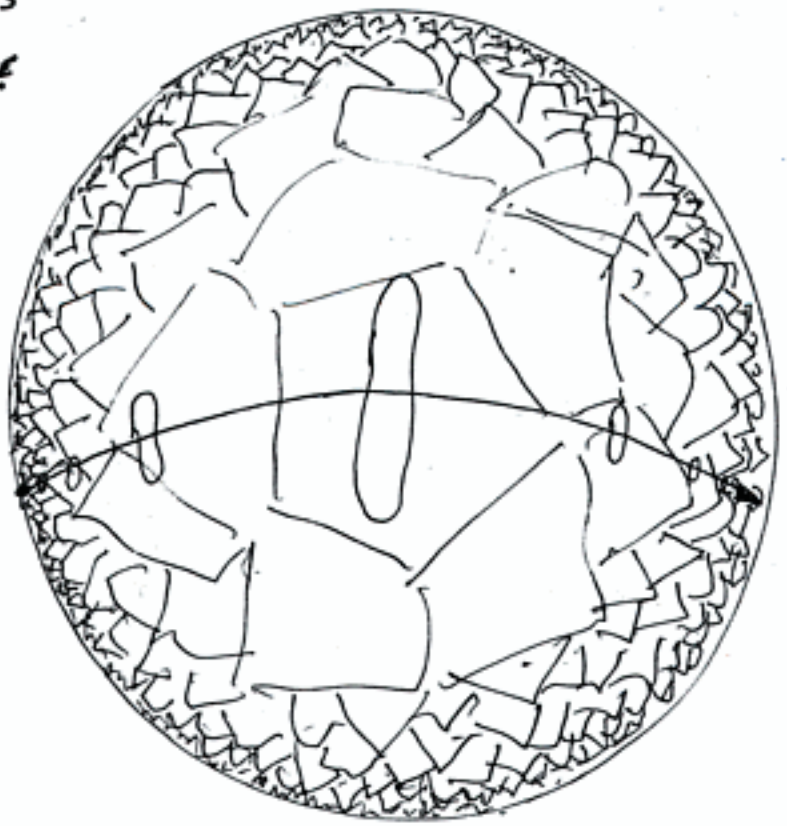
Now Use: $g_{YM}^2 N = R^4/l_s^4$

$$g_{YM}^2 = g_{st}$$

$$\frac{g_{st}^2 l_s^8}{R^5} = \frac{1}{G_5}$$

$$N_{DOF} = \text{Area}/G_5$$

THE RADIAL DIRECTION IS SCALE SIZE



$$UV \longrightarrow IR \longrightarrow UV \longrightarrow IR$$

HOLOGRAPHY + COSMOLOGY

$$ds^2 = a(t)^2 dx^i dx^i$$

$$S_H \leq A_H$$

TODAY $\quad S_H \sim 10^{80} \sim 10^{90}$

$\quad A_H \sim 10^{120}$

TOMMORROW

$$X_H \sim t^{1-p}$$

$$S_H \sim X_H^d = t^{d-dp}$$

$$A_H \sim (a X_H)^{d-1} \sim t^{d-1}$$

$$d-1 \geq d-dp$$

or

$$p \geq \frac{1}{d}$$

BOUND ON EXPANSION RATE

EQ OF STATE;

$$\text{PRESSURE} = \gamma\,(\text{ENERGY DENSITY})$$

$$a(t) \sim t^{\frac{2}{d(1+\gamma)}} = t^{p}$$

BOUND $\gamma \lesssim 1$

STANDARD CAUSAL BOUND

YESTERDAY;

EXTRAPOLATING BACKWARD ONE FINDS

$$\frac{S_H}{A_H} \approx 10^{-28}\left(\frac{t_d}{t}\right)^{1/2}$$

t_d = decoupling time

AT PLANCK TIME

$$\frac{S_H}{A_H} \sim 1$$