Title: Aspects of de Sitter Holography

Speakers: Leonard Susskind

Series: Quantum Fields and Strings

Date: September 14, 2021 - 2:00 PM

URL: https://pirsa.org/21090012

Abstract: Abstract: TBD

11:02 AM Tue Sep 14

$$\boxed{\text{SYK}(q=\sqrt{N}\,,\ T\sim J)}$$

~~k-LOCALITY~~

COMPLEXITY GROWTH HYPERFAST ?

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65%

Aspects of De Sitter Space

All Pages

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2

3

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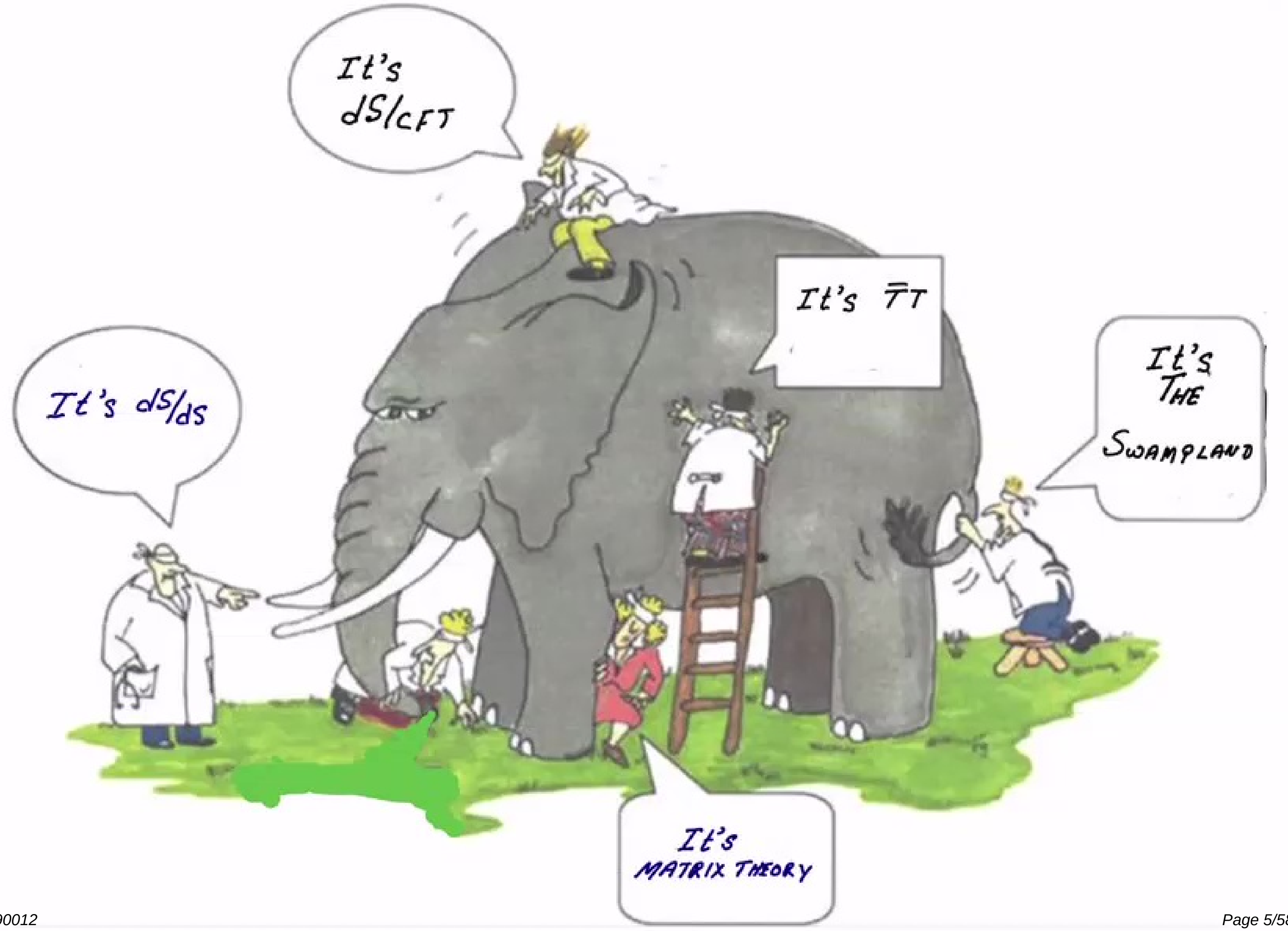
2 / 30


It's dS/CFT
It's $T\bar{T}$
It's dS/dS
It's THE SWAMPLAND
It's MATRIX THEORY

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SOME FRAGMENTARY CIRCUMSTANTIAL EVIDENCE

FOR dS-MATRIX DOF

BANKS, FIOL, MORRISE, FISCHLER, LS

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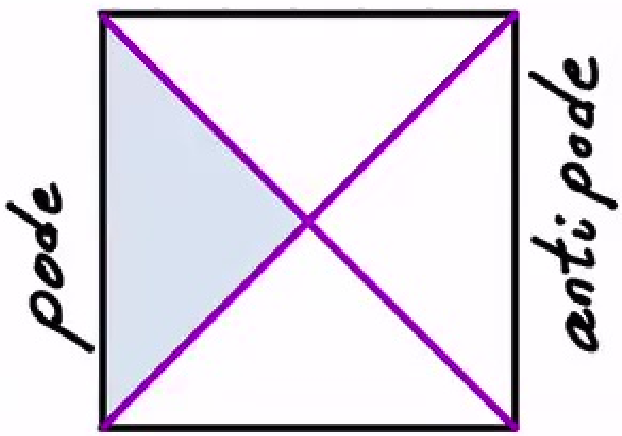
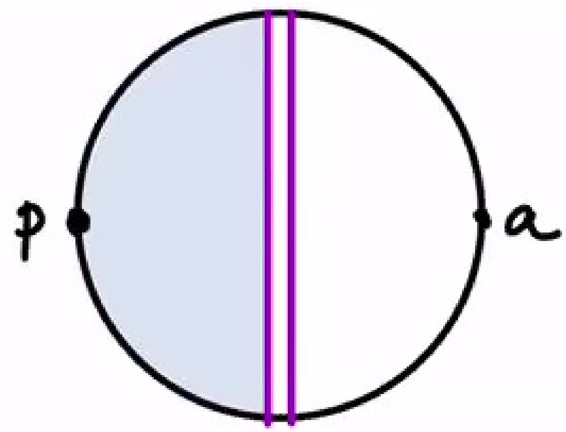
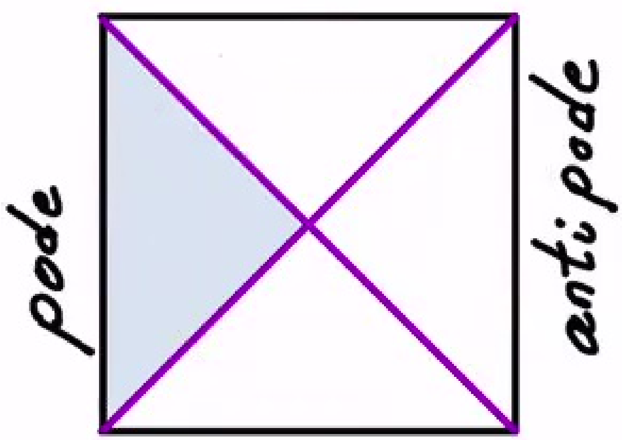
STATIC PATCH

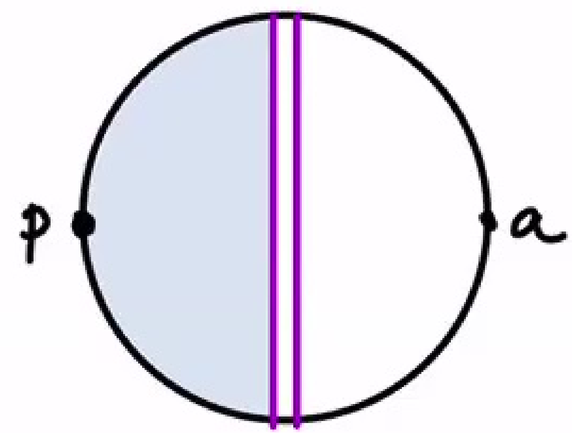
STATIC PATCH





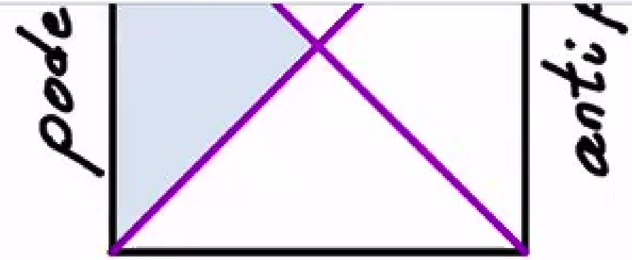
$$ds^2 = -f(r)\,dt^2 + \frac{dr^2}{f(r)} + r^2 d\Omega^2$$

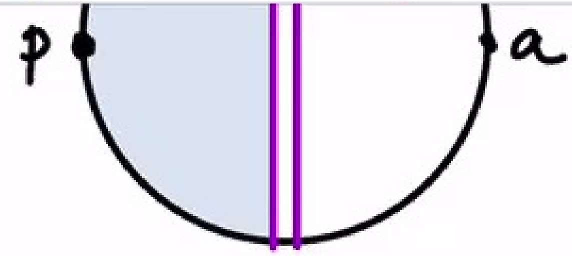




$$ds^2 = -f(r)\,dt^2 + \frac{dr^2}{f(r)} + r^2 d\Omega^2$$

$$f(r) = \left(1 - \frac{r^2}{R^2}\right)$$





$$ds^2 = -f(r)\,dt^2 + \frac{dr^2}{f(r)} + r^2 d\Omega^2$$

$$f(r) = \left(1 - \frac{r^2}{R^2}\right)$$

THERMODYNAMICS OF SP (4-dim)

$$T = \frac{1}{2\pi R}$$

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$$f(r) = \left(1 - \frac{r^2}{R^2}\right)$$

THERMODYNAMICS OF SP (4-dim)

$$T = \frac{1}{2\pi R}$$

$$S_0 = \frac{\pi}{G} R^2$$

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HIDDEN ASSUMPTIONS

UNITARY QUANTUM MECHANICS

HILBERT SPACE OF STATES

HAMILTONIAN

O(4,1) SYMMETRY

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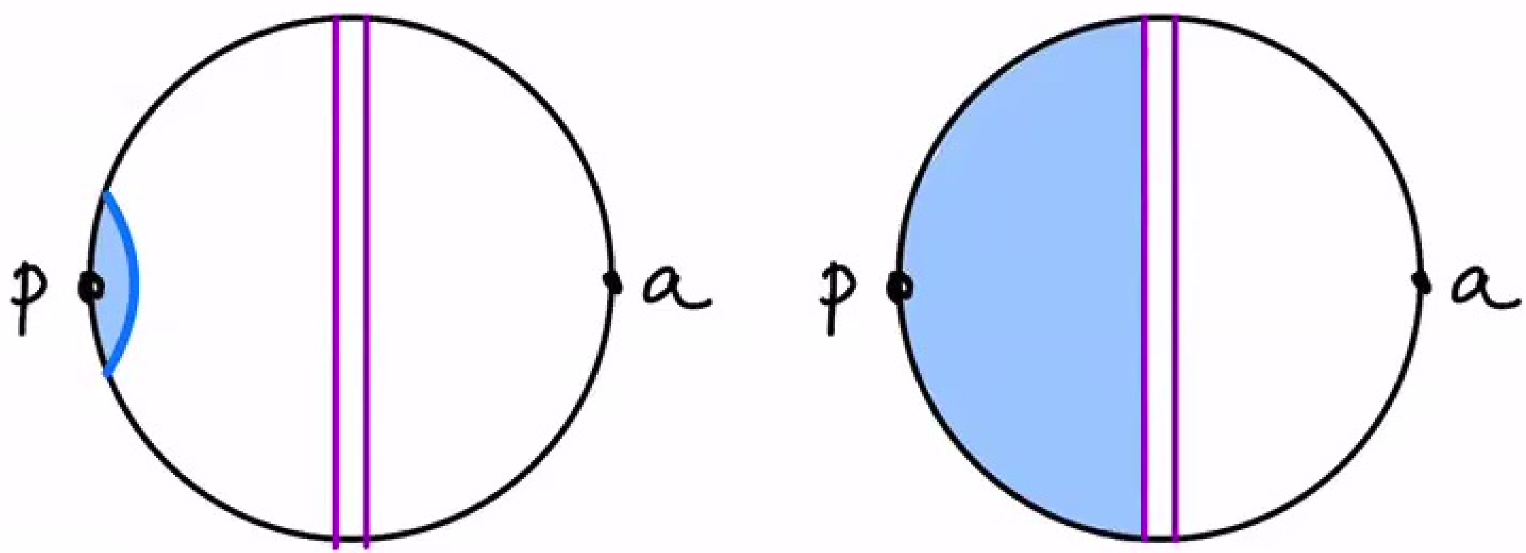
UNITARY QUANTUM MECHANICS

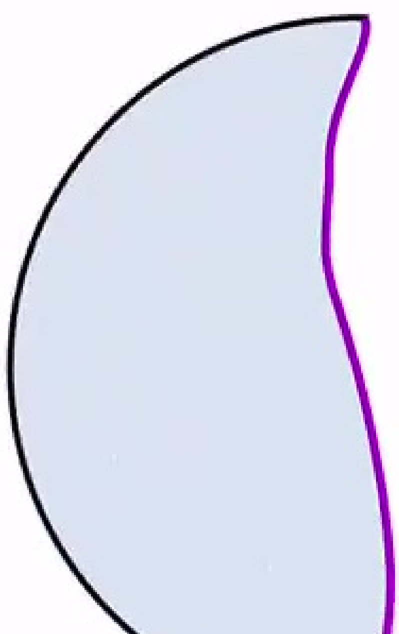
HILBERT SPACE OF STATES

HAMILTONIAN

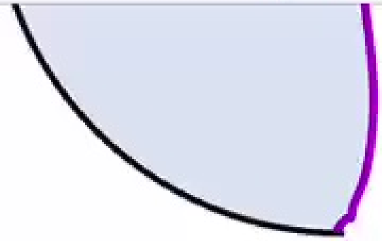
O(4,1) SYMMETRY

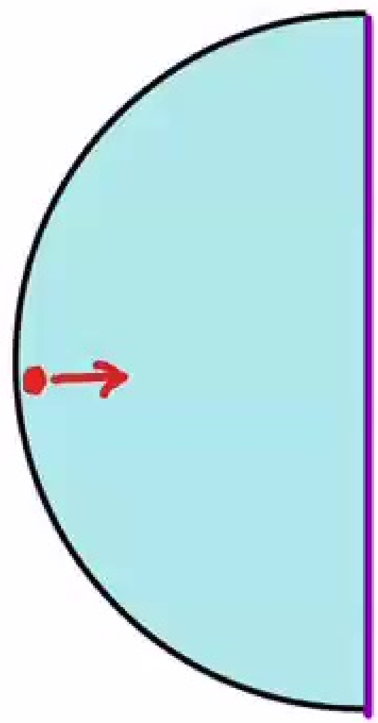


WHAT IS SIMPLE?



QUASINORMAL MODES





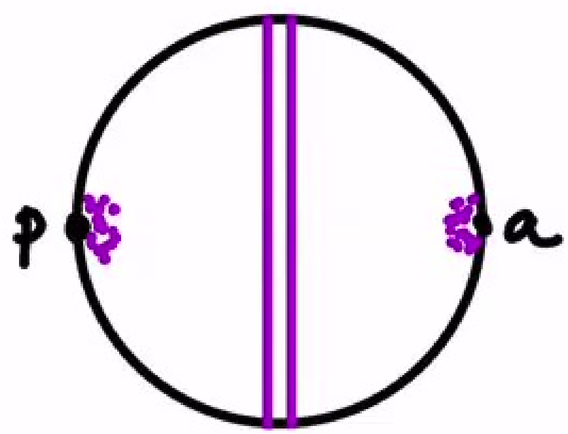
NOT SIMPLE

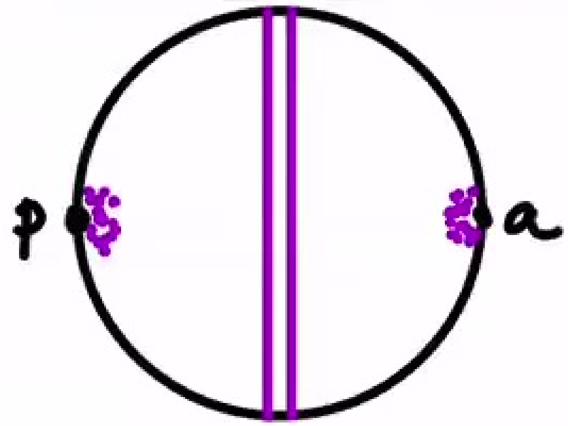
OPERATOR AT NODE

EVIDENCE FOR dS-MATRIX THEORY

ARXIV: 2109.01322

BOLTZMANN FLUCTUATIONS





dS-SCHWARZSCHILD

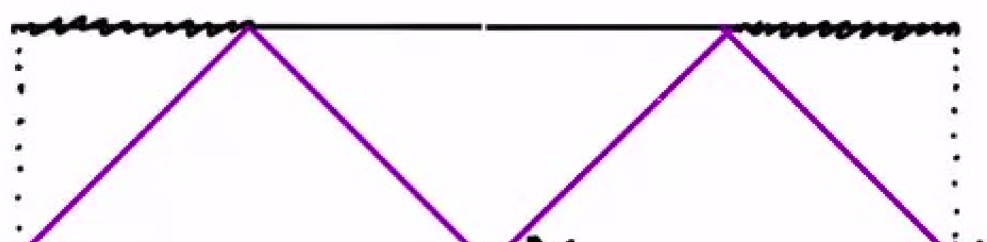
$$f(r) = 1 - \frac{r^2}{R^2} - \frac{2MG}{r}$$

$$f(r) = 1 - \frac{r^2}{R^2} - \frac{2MG}{r}$$

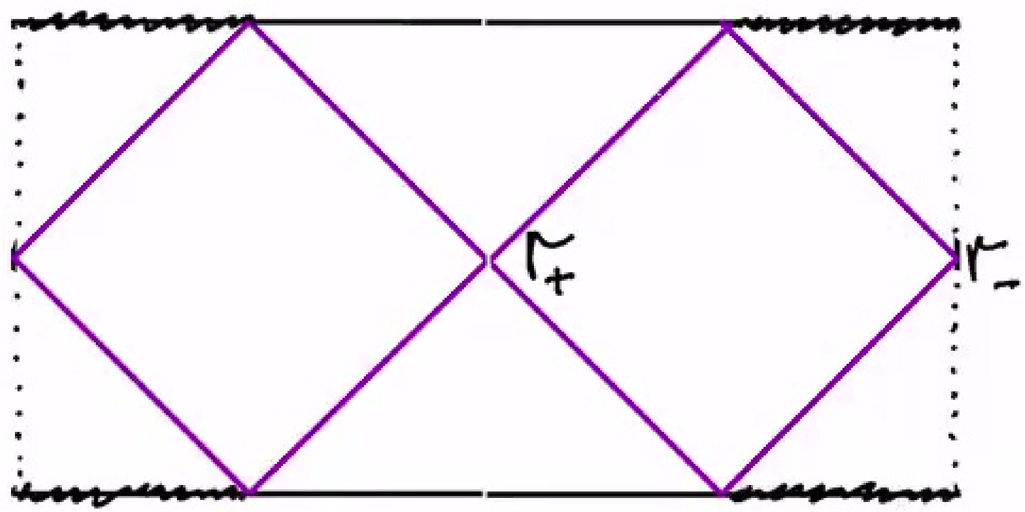
HORIZONS: $f(r) = 0$

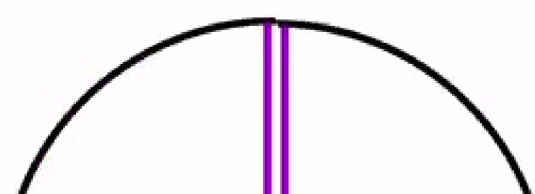
SMALL BLACK HOLES

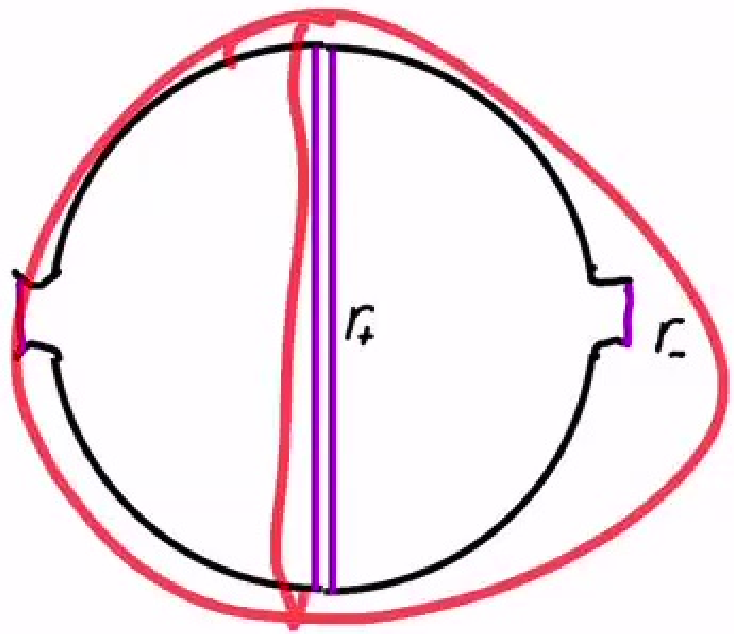
$2MG \ll R$ $\qquad$ $s \ll S_0$



$2MG \ll R$ $\qquad$ $s \ll S_0$

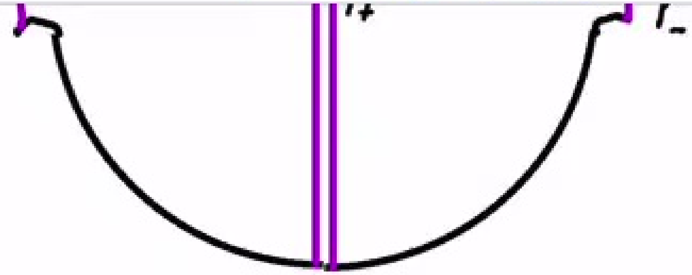






$$P = e^{-\Delta S}$$

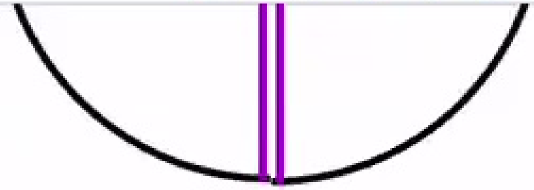
$$\Delta S = S_0 - S$$



$$P = e^{-\Delta S}$$

$$\Delta S = S_0 - S$$

$$\Delta S = \frac{\pi}{G}\left[R^2 - \left(r_+^2 + r_-^2\right)\right]$$



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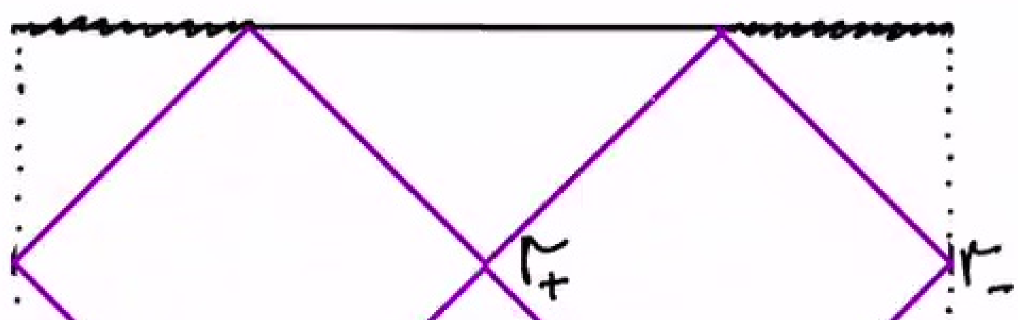
$$f(r) = 1 - \frac{r^2}{R^2} - \frac{2MG}{r}$$

HORIZONS: $f(r) = 0$

SMALL BLACK HOLES

$2MG \ll R \qquad S \ll S_0$



$$P = e^{-\Delta S}$$

$$\Delta S = S_0 - S$$

$$\Delta S = \frac{\pi}{G}\left[R^2 - \left(r_+^2 + r_-^2\right)\right]$$

$$= 2\pi R M$$ LEADING IN M

$$* \boxed{= \sqrt{S_0\, s}} *$$ LEADING IN s

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$$\Delta S = \frac{\pi}{G}\left[R^2 - \left(r_+^2 + r_-^2\right)\right]$$

$$= 2\pi R M$$ LEADING IN M

$$* \boxed{= \sqrt{S_0 s}} *$$ LEADING IN s

CLUE ?

dS-MATRIX THEORY BANKS, FIOL, MORRISE 2006

$$= 2\pi R M$$ LEADING IN M

$$* \boxed{= \sqrt{S_0\, s}} *$$ LEADING IN s

CLUE ?

dS-MATRIX THEORY

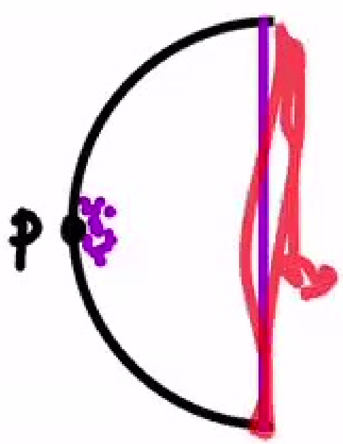
BANKS, FIOL, MORRISE 2006

LS 2011

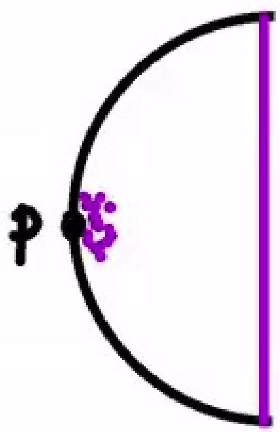
DOF = FINITE # MATRICES

$$A = \begin{pmatrix} a_{11} & a_{12} & a_{13} & \cdot & \cdot & a_{1N} \\ a_{21} & \cdot & & & & \\ \cdot & & \cdot & & & \\ \cdot & & & \cdot & & \\ \cdot & & & & \cdot & \\ a_{N1} & & & & & \cdot \end{pmatrix} \qquad S_0 = \sigma N^2$$

$N - m$ $\qquad$ m



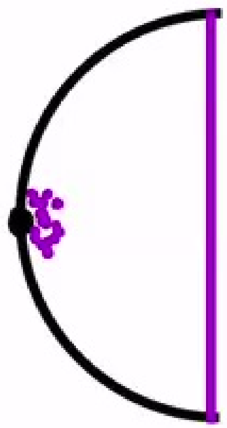
$$A = \begin{array}{c} \begin{array}{cc} \overbrace{\hphantom{a_{11}\quad a_{12}\quad a_{13}\quad \cdot}}^{N-m} & \overbrace{\hphantom{a_{**}\quad a_{**}}}^{m} \end{array} \\ \left(\begin{array}{cccc|cc} a_{11} & a_{12} & a_{13} & \cdot & 0 & 0 \\ a_{21} & \cdot & & & 0 & 0 \\ \cdot & & \cdot & & 0 & 0 \\ \cdot & & & \cdot & 0 & 0 \\ \hline 0 & 0 & 0 & 0 & a_{**} & a_{**} \\ 0 & 0 & 0 & 0 & a_{**} & a_{**} \end{array}\right) \end{array}$$



$$
A = \begin{array}{c}
\begin{array}{cccccc} \overbrace{\qquad\qquad\qquad\qquad}^{N-m} & & & & \overbrace{\qquad\quad}^{m} & \end{array} \\
\left(\begin{array}{cccc|cc}
a_{11} & a_{12} & a_{13} & \cdot & 0 & 0 \\
a_{21} & \cdot & & & 0 & 0 \\
\cdot & & \cdot & & 0 & 0 \\
\cdot & & & \cdot & 0 & 0 \\
\hline
0 & 0 & 0 & 0 & a_{**} & a_{**} \\
0 & 0 & 0 & 0 & a_{**} & a_{**}
\end{array}\right)
\end{array}
$$

$$S = \sigma (N - m)^2$$

$$s = \sigma m^2$$

P


$$A = \left(\begin{array}{cccc|cc} a_{11} & a_{12} & a_{13} & \cdot & 0 & 0 \\ a_{21} & \cdot & & & 0 & 0 \\ \cdot & & \cdot & & 0 & 0 \\ \cdot & & & \cdot & 0 & 0 \\ \hline 0 & 0 & 0 & 0 & a_{**} & a_{**} \\ 0 & 0 & 0 & 0 & a_{**} & a_{**} \end{array}\right)$$

$$S = \sigma (N - m)^2$$

$$s = \sigma m^2$$

$$\Delta S = \sigma N^2 - S - s$$

$$\Delta S = 2 \sigma N m$$

LEADING IN m

$$S = \sigma (N-m)^2$$

$$s = \sigma m^2$$

$$\Delta S = \sigma N^2 - S - s$$

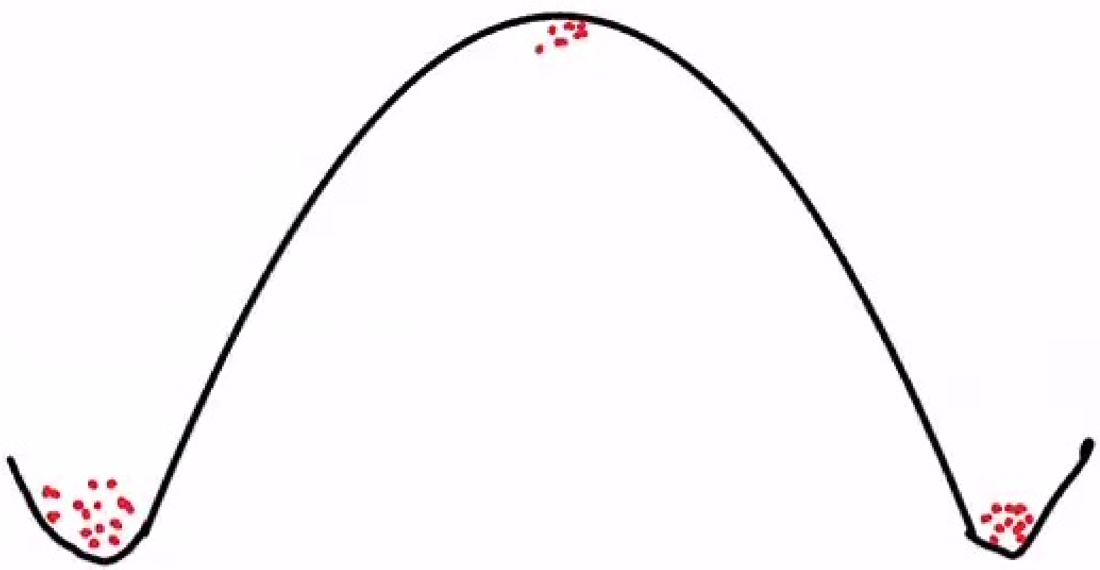
$$\Delta S = 2\sigma N m$$

LEADING IN m

$$\boxed{= 2\sqrt{S s}}$$

2?

Toy MODEL



$$S_0 = N \log V$$

$$S = (N-m)\log V + m \log v$$

$$\Delta S = m \log V/v = 2m \log \frac{s}{s_0}$$

$$\Delta S \sim m \log \frac{m}{N} \sim s \log \frac{s}{S}$$

COMPARED WITH

$$\Delta S = 2\sigma N m \sim \boxed{\sqrt{s S}}$$

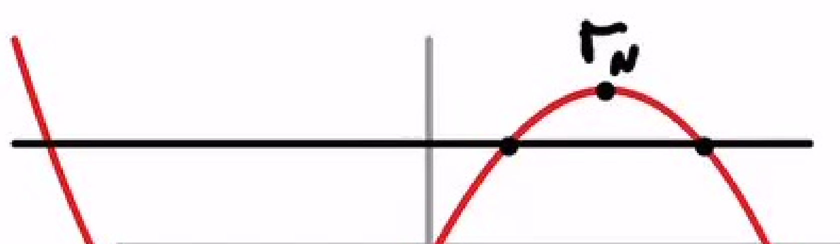
LARGE BLACK HOLES

LARGE BLACK HOLES

$$s/S_0 \sim 1$$

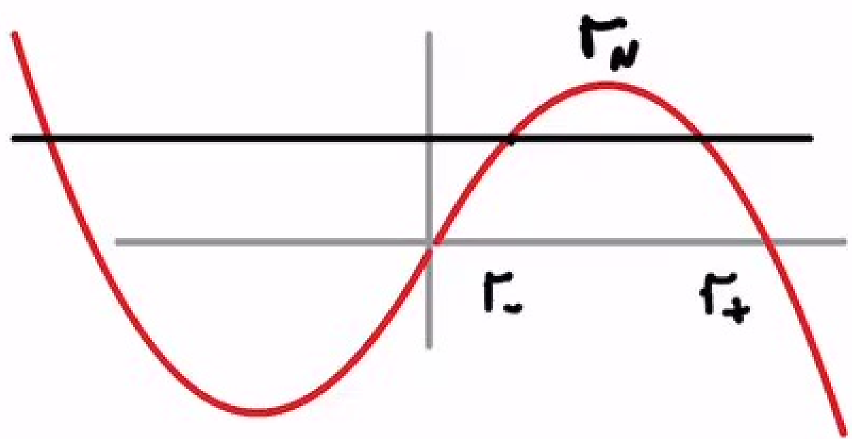
$$f(r) = 1 - \frac{r^2}{R^2} - \frac{2MG}{r}$$

$$r f(r) = r - \frac{r^3}{R^2} - 2MG$$

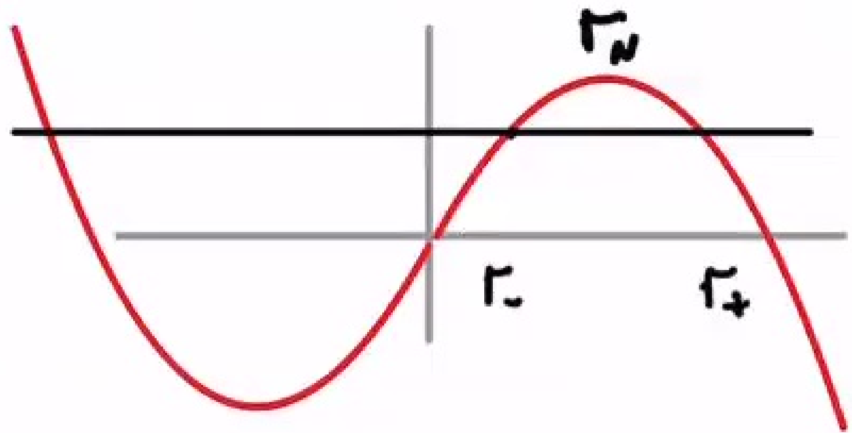


$$f(r) = 1 - \frac{r^2}{R^2} - \frac{2MG}{r}$$

$$r f(r) = r - \frac{r^3}{R^2} - 2MG = 0$$

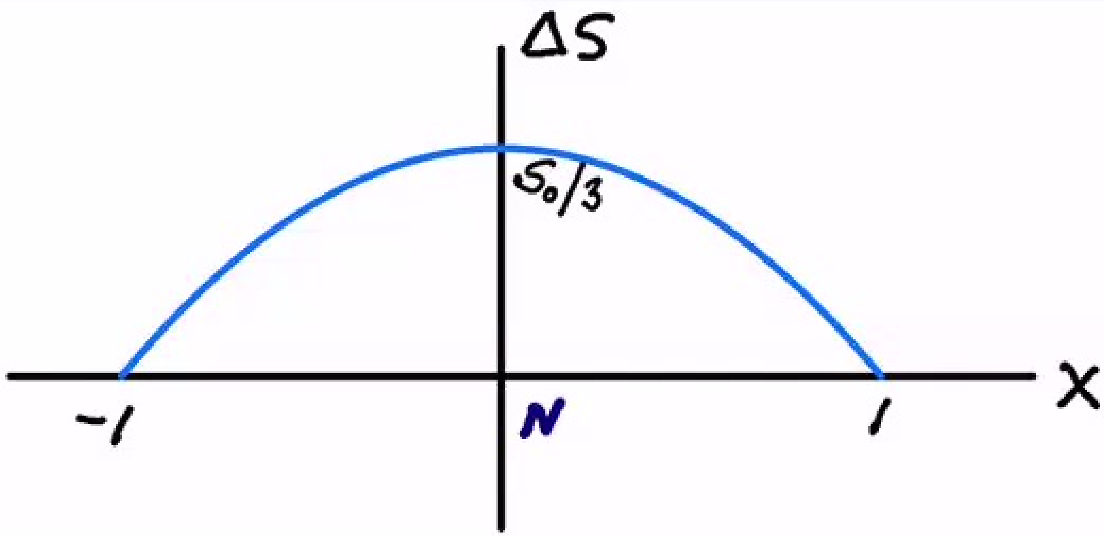


$$x = r \quad r$$



$$x = \frac{r_- - r_+}{R}$$

$$-1 < x < 1$$



$$\ast \quad \boxed{\Delta S = \Delta S_N (1 - x^2)} \quad \ast$$

$$\Delta S_N = \frac{1}{3} S_0$$

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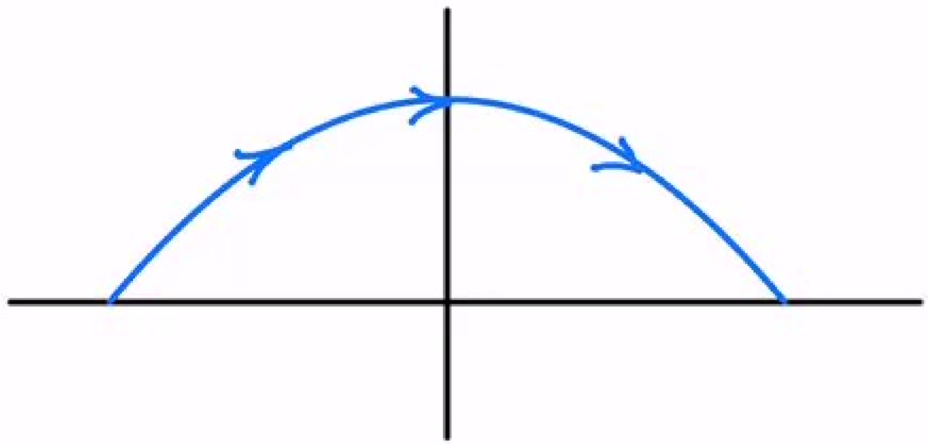
INSIDE - OUT TRANSITION



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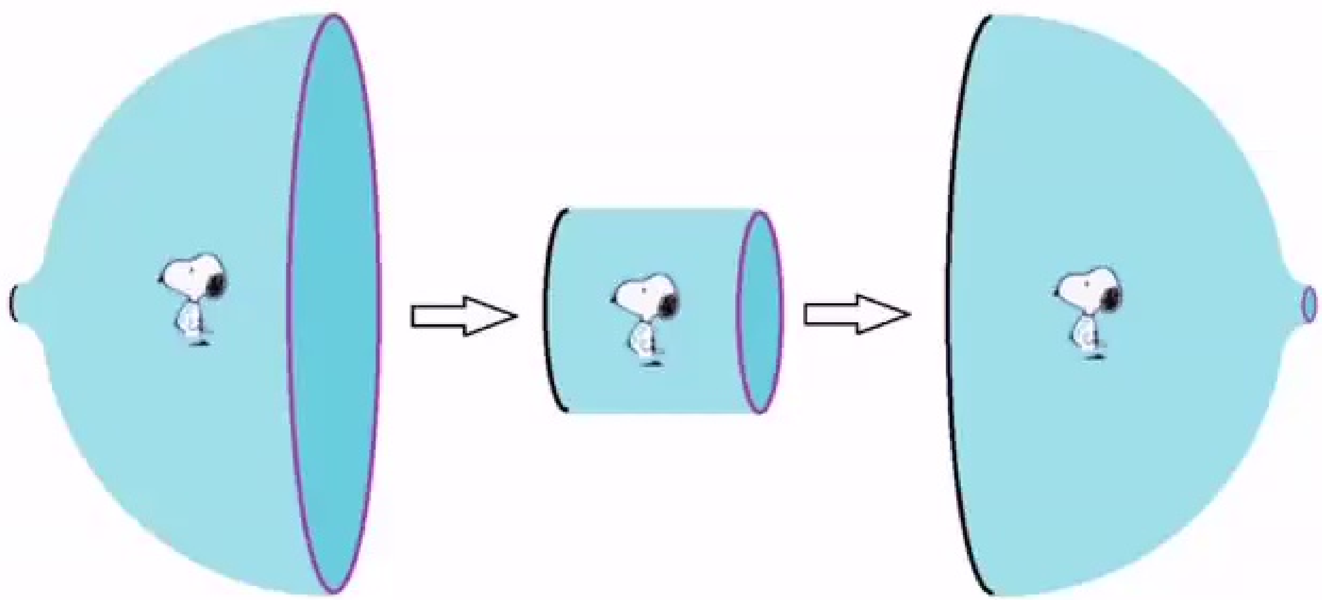

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$$\text{PROB} = e^{-\Delta S} = e^{-S_0/3}$$

$$
\begin{array}{c}
\overbrace{\qquad\qquad\qquad}^{\frac{N}{2}} \; \overbrace{\qquad\qquad\qquad}^{\frac{N}{2}} \\
\left(\begin{array}{ccc|ccc}
a & a & a & 0 & 0 & 0 \\
a & a & a & 0 & 0 & 0 \\
a & a & a & 0 & 0 & 0 \\
\hline
0 & 0 & 0 & a & a & a \\
0 & 0 & 0 & a & a & a \\
0 & 0 & 0 & a & a & a
\end{array}\right)
\end{array}
$$

NARIAI

$$\Delta S = \sigma m (N-m)$$

$$S \sim r^2$$

$$
\left(\begin{array}{ccc|ccc}
0 & 0 & 0 & a & a & a \\
0 & 0 & 0 & a & a & a \\
0 & 0 & 0 & a & a & a
\end{array}\right)
$$

$$\Delta S = \sigma m (N-m)$$

$$S \sim r^2$$

$$X = \frac{\sqrt{S_-} - \sqrt{S_+}}{\sqrt{S_0}} = \frac{m-(N-m)}{N}$$

$$= \frac{2m}{N} - 1$$

$$\Delta S = \sigma m (N-m)$$

$$S \sim r^2 \qquad x = \frac{r_- - r_+}{R}$$

$$x = \frac{\sqrt{S_-} - \sqrt{S_+}}{\sqrt{S_0}} = \frac{m-(N-m)}{N}$$

$$= \frac{2m}{N} - 1$$

$$\boxed{\Delta S = \Delta S_N (1-x^2)}$$

$$\Delta S = \sigma m (N-m)$$

$$S \sim r^2$$

$$x = \frac{r_- - r_+}{R}$$

$$x = \frac{\sqrt{S_-} - \sqrt{S_+}}{\sqrt{S_0}} = \frac{m-(N-m)}{N}$$

$$= \frac{2m}{N} - 1$$

$$\boxed{\Delta S = \Delta S_N (1-x^2)}$$

$$x = \frac{\cdots}{\sqrt{S_0}} = \frac{\cdots}{N}$$

$$= \frac{2m}{N} - 1$$

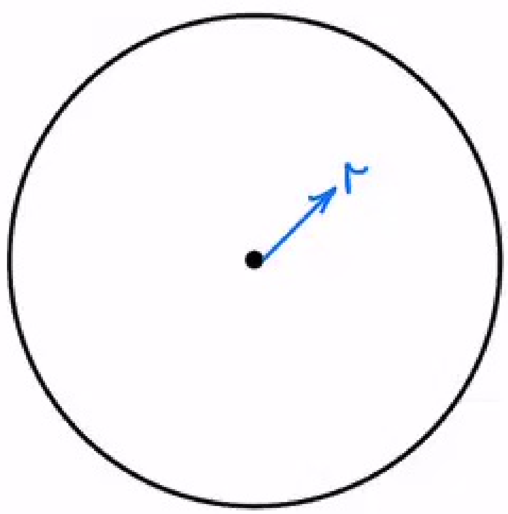
$$\boxed{\Delta S = \Delta S_N \left(1 - x^2\right)}$$

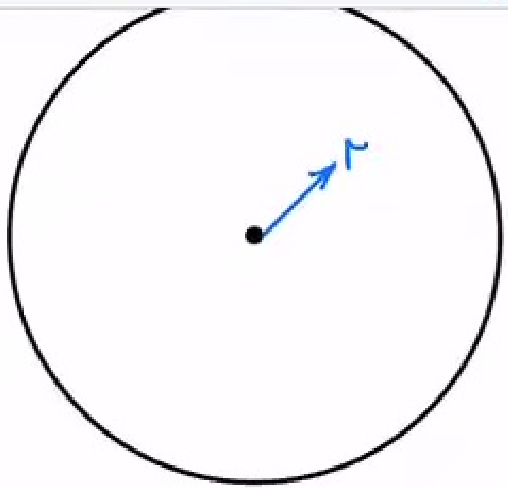
$$\Delta S_N = S_0/2 \quad ?$$

DYNAMICS OF CONSTRAINTS

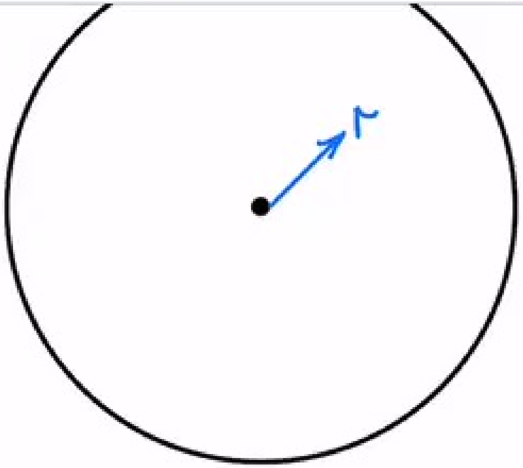
$$\Delta S_N = S_0/2 \quad ?$$

DYNAMICS OF CONSTRAINTS





$$\mathcal{R} = \begin{pmatrix} r_{11} & r_{12} & r_{13} & \cdot & \cdot & r_{1N} \\ r_{21} & \cdot & & & & \\ \cdot & & \cdot & & & \\ \cdot & & & \cdot & & \\ \cdot & & & & \cdot & \\ r_{N1} & & & & & \cdot \end{pmatrix}$$



$$\mathcal{R} = \begin{pmatrix} r_{11} & r_{12} & r_{13} & \cdot & \cdot & r_{1N} \\ r_{21} & \cdot & & & & \\ \cdot & & \cdot & & & \\ \cdot & & & \cdot & & \\ \cdot & & & & \cdot & \\ r_{N1} & & & & & \cdot \end{pmatrix}$$

$$\begin{pmatrix} \cdot & & \cdot & \\ \tilde{r}_{N1} & & & \cdot \end{pmatrix}$$

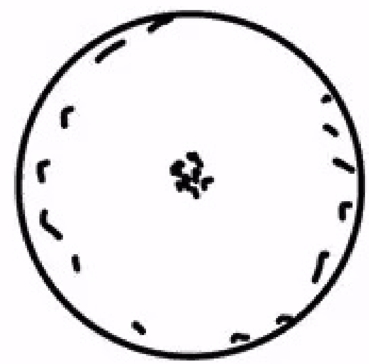
$$L = \sum \mathrm{Tr}\left(C^2 R^4 \dot{A}^2 - [\mathcal{R}, A][A, \mathcal{R}] \right) + \cdots\cdots$$

$$\mathcal{R} = \left(\begin{array}{ccccc|cc} R & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & R & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & R & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & R & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & R & 0 & 0 \\ \hline 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{array}\right)$$

$$\begin{pmatrix} \cdot & & \cdot \\ r_N & & \cdot \end{pmatrix}$$

$$L = \sum Tr\left(C^2 R^4 \dot{A}^2 - [\mathcal{R}, A][A, \mathcal{R}]\right) + \cdots\cdots$$

$$\mathcal{R} = \left(\begin{array}{ccccc|cc} R & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & R & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & R & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & R & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & R & 0 & 0 \\ \hline 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{array}\right)$$



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$$L = c^2 R^4 \dot{a}_{iJ}\, \dot{a}_{Ji} - R^2 a_{iJ}\, a_{Ji} + \cdots$$

$$\omega = \frac{1}{cR}$$

$$T = \frac{1}{2\pi R}$$

IF $\omega \gg T$ THE a_{iJ} ARE FROZEN

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IF $\omega \gg T$ THE a_i J ARE FROZEN INTO GROUND STATE AND CARRY NO ENTROPY (AS PREVIOUSLY ASSUMED).

ENTROPY $S \sim \sigma^2$.

SMALL BLACK HOLES

$$\Delta S = 2\frac{\sigma'}{\sigma}\sqrt{\Delta S} \approx \sqrt{\Delta\sigma}$$

$$\frac{\sigma'}{\sigma} \approx \frac{1}{2}$$

$$\approx \frac{1}{3} \int_0 (1-x^2)$$

$$\boxed{\frac{\sigma'}{\sigma} \approx \frac{2}{3}}$$

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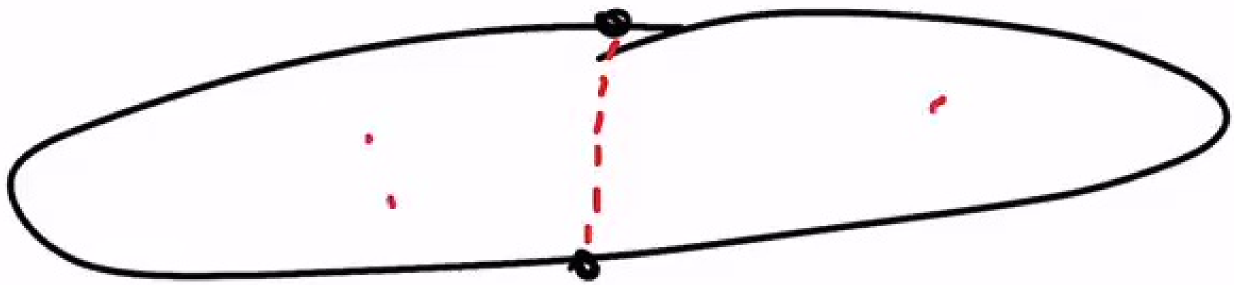

Entropy in De Sitter

dS-RT?

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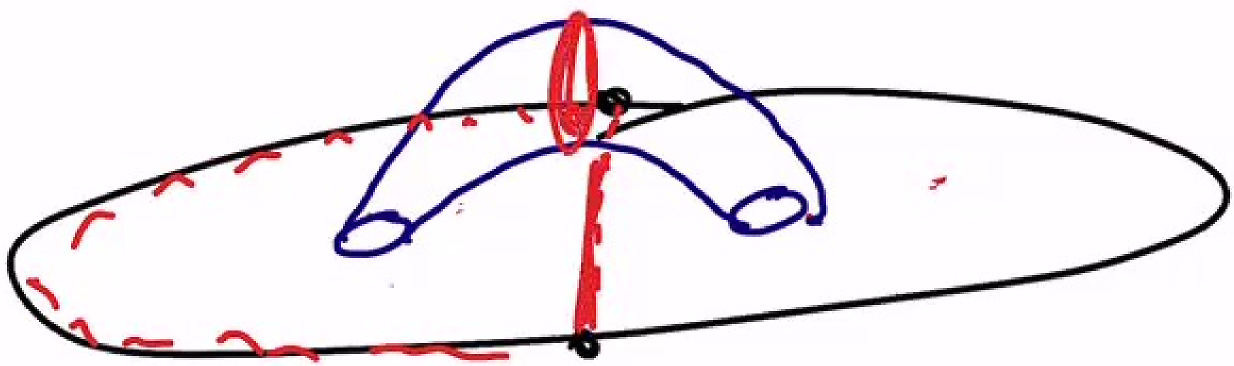
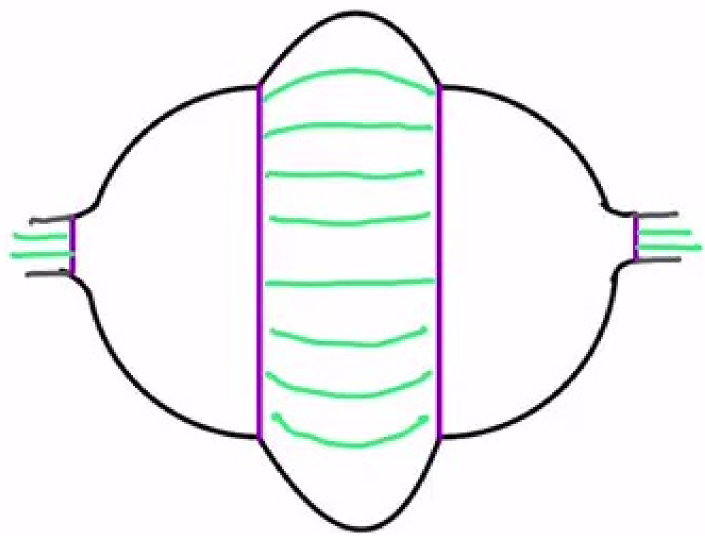


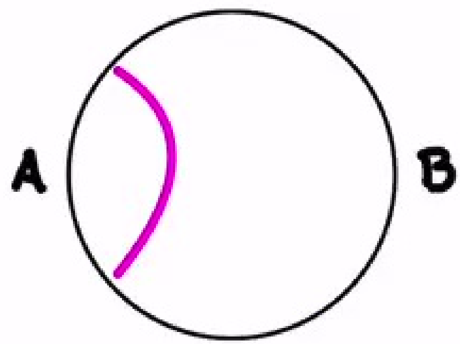
ENTROPY IN DE SITTER

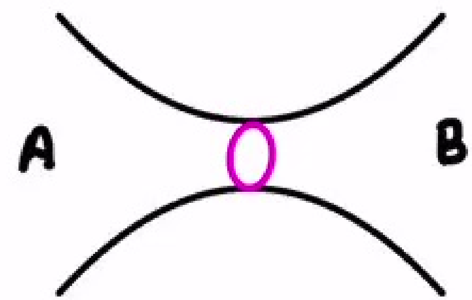
dS-RT ?

dS BLACK HOLE



DIVIDE BOUNDARY INTO 2 SUBSETS

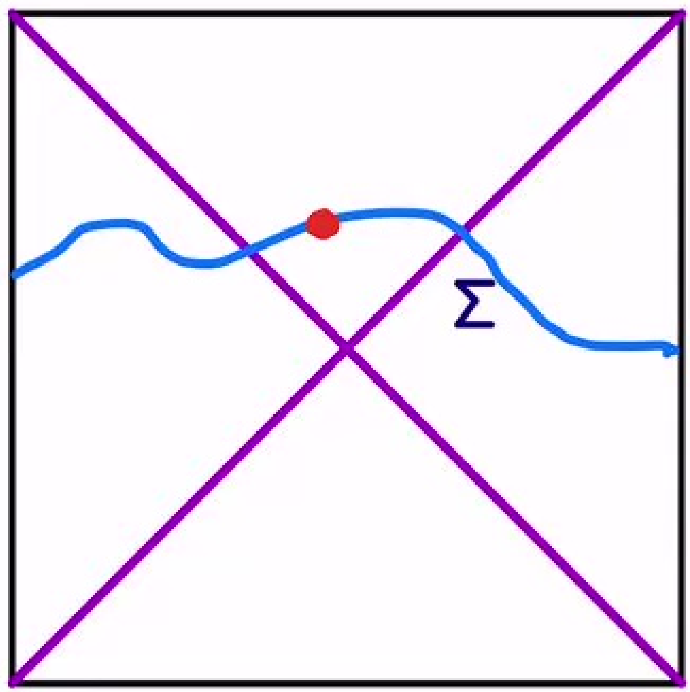




$$\boxed{S_{ENT} = \frac{A_{MIN}}{4G}}$$

R-T

A_{MIN} = MIN AREA OF SURFACE



$$\boxed{S_{ENT} = \frac{A_{\max\min}}{4G}}$$ HRT