Fundamental Strings and Black Holes

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Introduction

- Fundamental Strings (F1) at large g_s form Black Holes (BH) $M \gg \frac{M_s}{g_s^2}$

- As $g_s \to 0$ they become Free $(M_s \ll) M \ll \frac{M_s}{g_s^2}$

- In the extremal (say, 4-d) case the near horizon background ($AdS_2 \times S^2$) is g_s-independent

Hence, $AdS_2 \times S^2$ provides a (dual) description of the perturbative F1's thermodynamics

Dabholkar

Q: is there a worldsheet CFT background dual (in an appropriate sense) to perturbative F1's w/ generic charge q?

$$q \equiv \begin{pmatrix} q_L \\ q_R \end{pmatrix} = \frac{n}{R} \pm \frac{wR}{\alpha'}$$

Today:

Proposal for such an Exact Worldsheet CFT

In particular, in the Extremal case we will find the exact CFT background corresponding to small BHs

Moreover, we will find the exact CFT corresponding to the near horizon of BHs w/ generic electric and magnetic charges, hence deriving properties of such Dyonic BHs Exactly in α' both for BPS as well as Non-BPS BHs

- We shall begin by studying the case w/ generic electric and magnetic charges, and later will turn off the magnetic charges

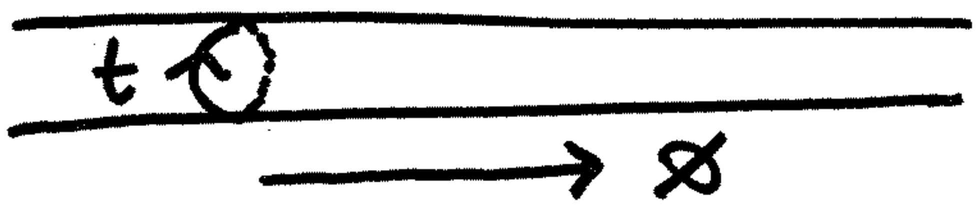
- Consider, say, the Heterotic String on

$$\mathbb{R}^{3,1} \times S^1 \times \tilde{S}^1 \times M_4$$

Heterotic String on $\mathbb{K}^{\text{"1"}} \times \tilde{S}^1 \times S^1 \times M_4$

<u>Add magnetic charge:</u>

$\tilde{W}$ NS5-branes on $S^1 \times M_4$

CHS 

w/ Linear Dilaton

$$\Phi = -\frac{Q}{2}\phi$$

$$\mathbb{R}_t \times \mathbb{R}_\phi \times \underline{SU(2)} \times S^1 \times M_4$$

BPS

$\tilde{N}$ KK-monopoles on $S^1 \times M_4$

$$\frac{SU(2)}{\mathbb{Z}(\tilde{N})_L}$$

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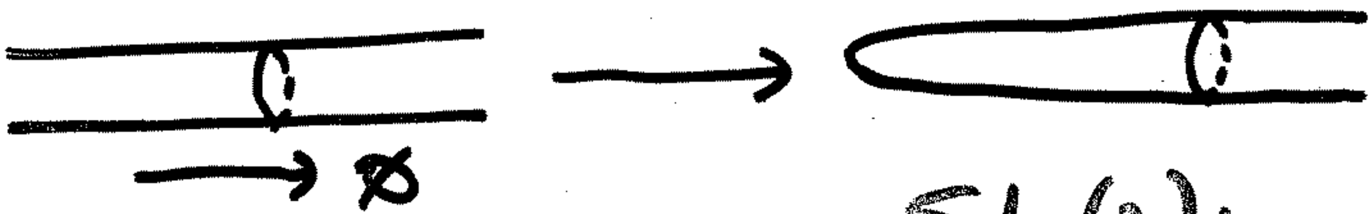
Add Energy M

$l_s \simeq 1$

$g_s^2 \ll 1$

$$M \ll \frac{1}{g_s^2}$$



ms $\mathbb{R}_\phi \times \mathbb{R}_t \longrightarrow \dfrac{SL(2)_k}{U(1)}$

2-d BH

Altogether:
near-extremal system $(\tilde{W}, \tilde{N}; M)$
w/ near-horizon CFT

$$\frac{SL(2)_k}{U(1)} \times S^1 \times \frac{SU(2)_k}{\mathbb{Z}(N)_L} \times M_4$$

$k = \tilde{N}\tilde{W} + 2 \qquad g^2_{hor.} \simeq 1/M$

Add F1 charge (n,w) on S^1:

- Boost along $S^1 \mapsto n$
- T-duality -‖- $\mapsto n \to w$
- Boost $\mapsto (n,w)$

we get

$$\frac{SL(2)}{U(1)} \times S^1 \longmapsto \frac{SL(2)_k \times U(1)}{U(1)}$$

2-d BH w/ 2 charges

$$J_L = J \sin\alpha_L + J^3 \cos\alpha_L$$
$$J_R = \bar{J} \sin\alpha_R + \bar{J}^3 \cos\alpha_R$$

$$\sin\alpha_{L,R} = \frac{q_{L,R}}{M} \qquad q_{L,R} = \frac{n}{R} \pm \frac{wR}{\alpha'}$$

Entropy:

$$S = \pi \ell_s \left(\sqrt{(k+2)(M^2 - q_L^2)} + \sqrt{k(M^2 - q_R^2)} \right)$$

$$k = \tilde{N}\tilde{W} + 2$$

$M^2 - q^2 \gg 1$
Exact in $\alpha' = \ell_s^2$

Special cases:

1. Extremal
2. very extremal
3. $\tilde{N} = \tilde{W} = 0$: small BHs

Extremal

$M^2 = q_R^2$, generic q_L BPS

$M^2 = q_L^2 - 1$, -॥- q_R Non-BPS

$$\underbrace{\frac{SL(2)\times U(1)}{U(1)}}_{\boxed{AdS_2}\times S^1} \times \underbrace{\frac{SU(2)}{\mathbb{Z}(\tilde{N})_L}}_{S^2\times\tilde{S}^1}$$

$$ds^2 = R^2_{Ads}\left(\frac{du^2}{u^2} - u^2 dt^2\right) + R^2_{S^2}\left(d\theta^2 + \sin^2\theta\, d\phi^2\right)$$

$$R^2_{Ads} = R^2_{S^2} = \frac{k\alpha'}{4} \qquad k = \tilde{N}\tilde{W} + 2$$

$$\frac{R^2}{\alpha'} = \left|\frac{n}{w}\right| \qquad \frac{\tilde{R}^2}{\alpha'} = \frac{\tilde{W}}{\tilde{N}}$$

$$g_4^2 = \sqrt{\frac{k}{|nw|}} \qquad F_{ut}^{(G,B)} \simeq (n, w)$$

$AdS_2 \times S^2$ $\qquad F_{\theta\phi}^{(\tilde{G},\tilde{B})} \simeq (\tilde{N}, \tilde{W})\sin\theta$

$$S_{SUSY} = 2\pi\sqrt{|nw|(\tilde{N}\tilde{W}+4)}$$

$$S_{\underline{NON}-SUSY} = 2\pi\sqrt{|nw|(\tilde{N}\tilde{W}+2)}$$

- Relation w/ other works:

Sen λR^2_{GB} $\leftrightarrow$ agree in the SUSY case

cdWM $\lambda\left(R^2_{Weyl} + \text{terms w/ fields in the Weyl mult. required by SUSY}\right)$

⋮

Extremal, non-BPS Kraus-Larsen Sahoo-Sen

② Very extremal

$M^2 = q_R^2 = q_L^2 - 1$ (say, $n = 0$)

$$(AdS_3)_k \times \frac{SU(2)_k}{\mathbb{Z}(N)_L} \times M_4 \qquad \text{KLL}$$

w/ $g_3^{-2} = \sqrt{k}\,|w|$

3) Small BH (perturbative F1)

$\tilde{N} = 0$

$$\frac{SL(2)_2 \times U(1)}{U(1)} \times \{\bar{\Psi}_1, \bar{\Psi}_2, \bar{\Psi}_3\} \times M_4$$

$$S_{BH} = \pi \ell_s \sqrt{2} \left(\sqrt{2(M^2 - q_L^2)} + \sqrt{M^2 - q_R^2} \right)$$

$$= S_{F1} \, !$$

for any $(M; q_L, q_R)$

Proposal (say, in type II):

$$\frac{SL(2)_2 \times U(1)}{U(1)} \times \mathcal{M}_5 \text{ is the}$$

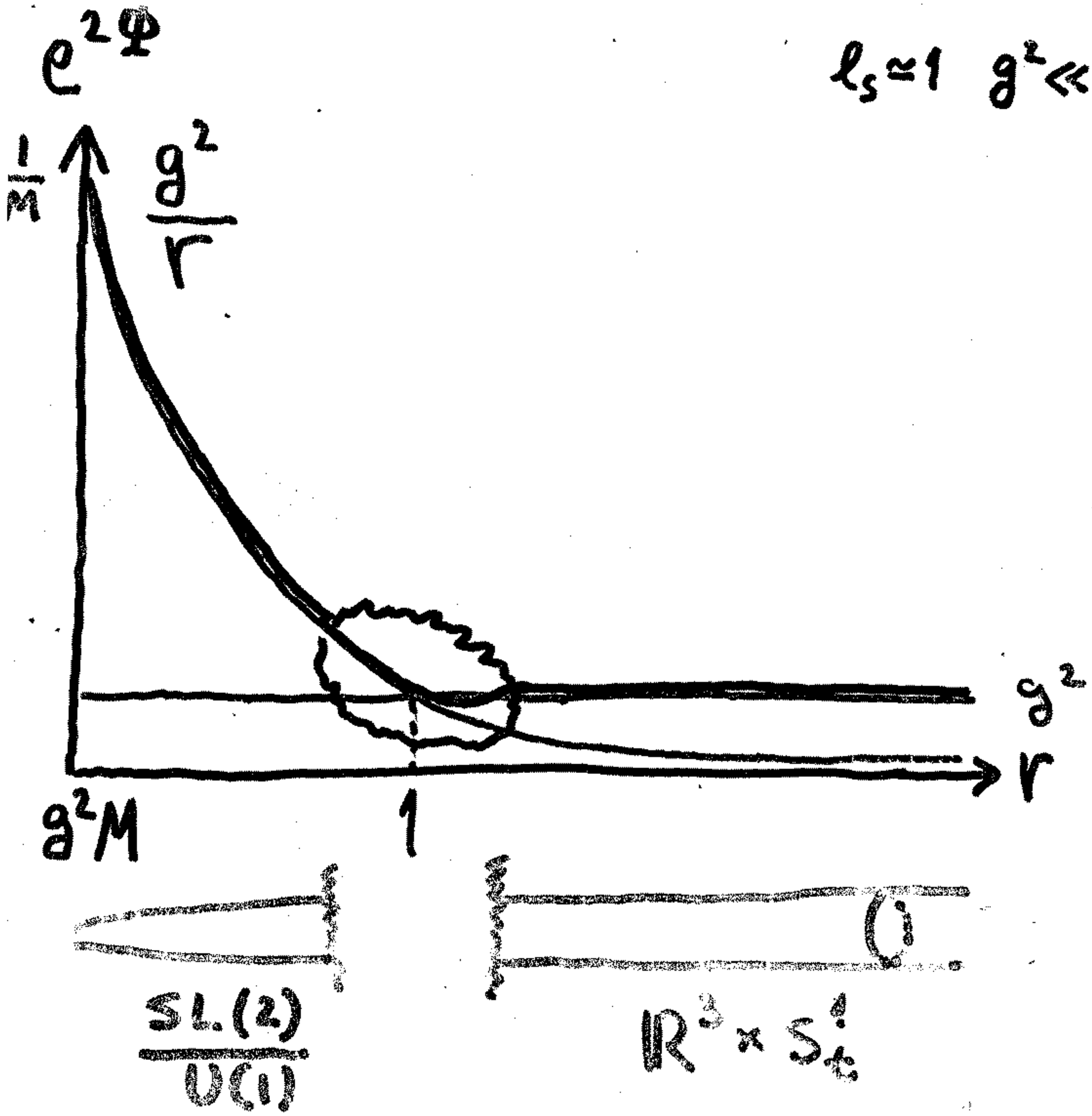
near-horizon CFT of perturbative F1's ($M \ll 1/g_s^2$) w/ (n,w) charges

- $q_L = q_R = 0$:

4-d Schw. $\xrightarrow{g_s \to 0}$ $\frac{SL(2)_2}{U(1)} \times \mathcal{M}_6$

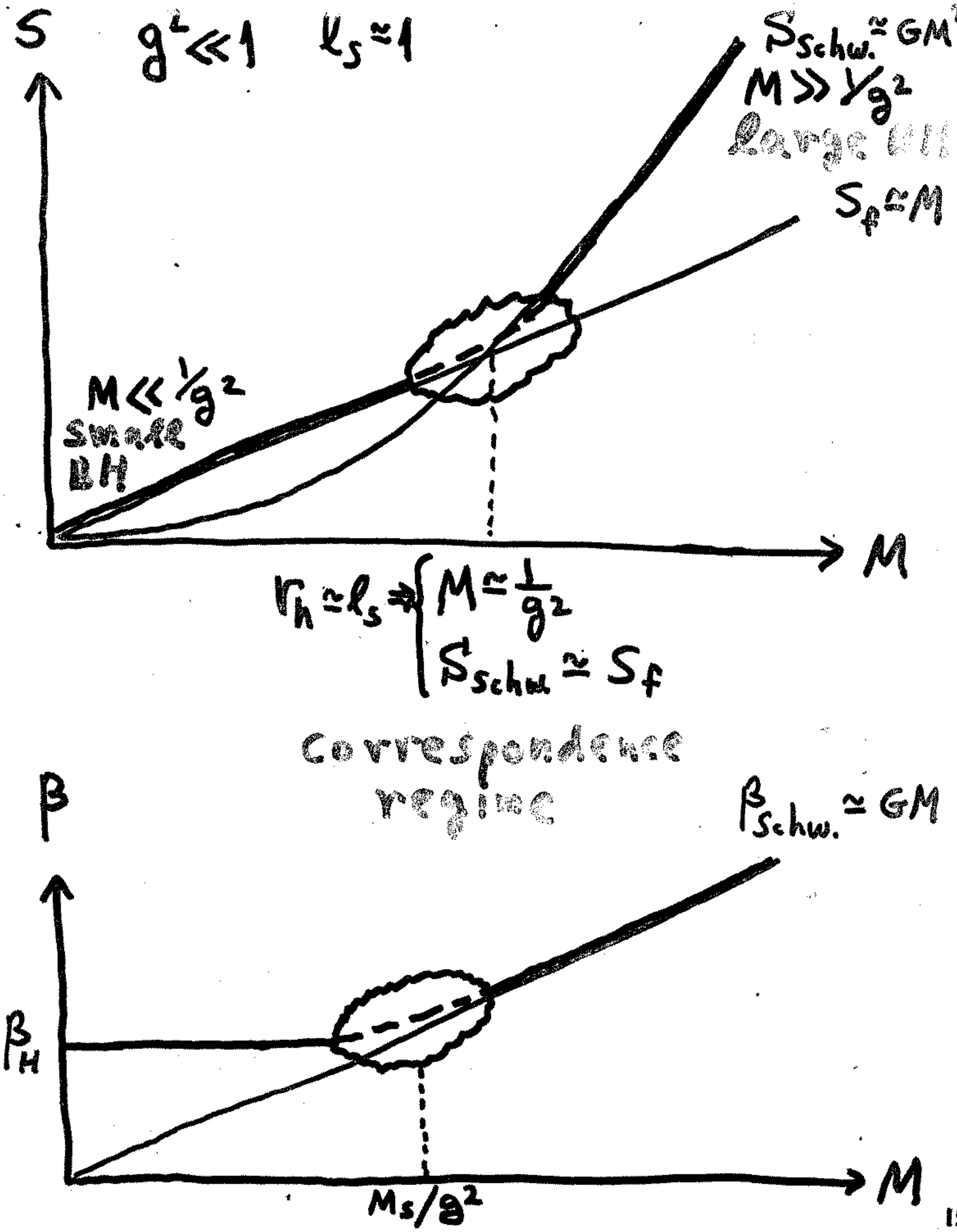
w/ $g^2_{hor.} \simeq \frac{1}{M}$

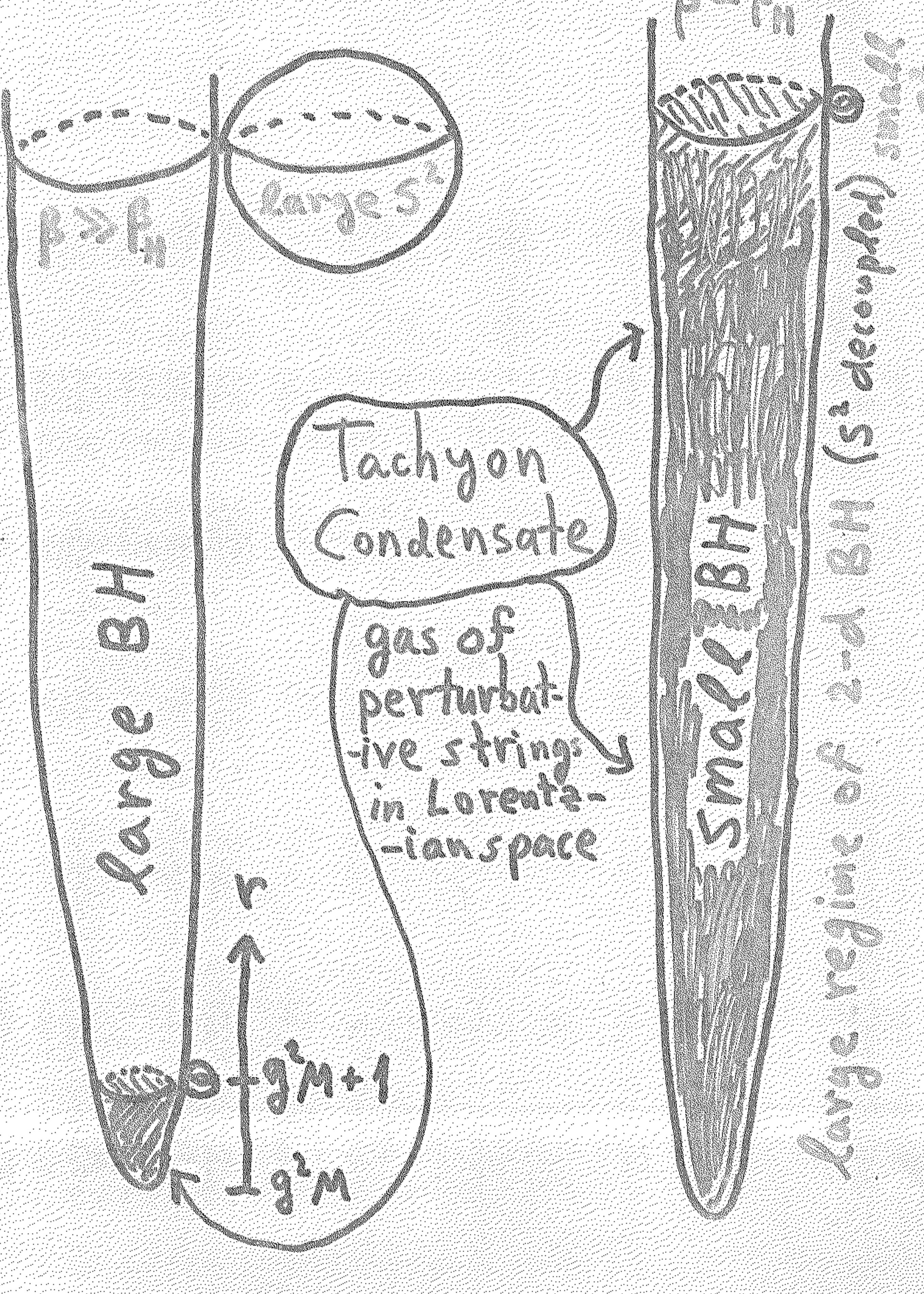
$\ell_s \simeq 1 \quad g^2 \ll 1$



$$ds^2 = -f\,dt^2 + \frac{d\rho^2}{f\rho^2}$$
$$f = 1 - \frac{2M}{\rho}$$
$$e^{-2\Phi} = \rho \simeq \frac{r}{g^2}$$

$$ds^2 = -f\,dt^2 + \frac{dr^2}{f} + r^2 d\Omega_2$$
$$f = 1 - \frac{2GM}{r}$$
$$G \simeq g^2$$
$$r_h \simeq g^2 M$$


S
$g^2 \ll 1$ $l_s \simeq 1$
$S_{Schw.} \simeq GM^2$
$M \gg 1/g^2$
large BH
$S_f \simeq M$
$M \ll 1/g^2$
small BH
M
$r_h \simeq l_s \Rightarrow \begin{cases} M \simeq \frac{1}{g^2} \\ S_{Schw} \simeq S_f \end{cases}$
correspondence regime
β
$\beta_{Schw.} \simeq GM$
β_H
M
M_s/g^2


$\beta = \beta_H$
small S^1
large S^1
$\beta \gg \beta_H$
large BH
Tachyon Condensate
gas of perturbat-
-ive strings
in Lorentz-
-ian space
r
g^2M+1
g^2M
small BH
Large regime of 2-d BH (S^1 decoupled)