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

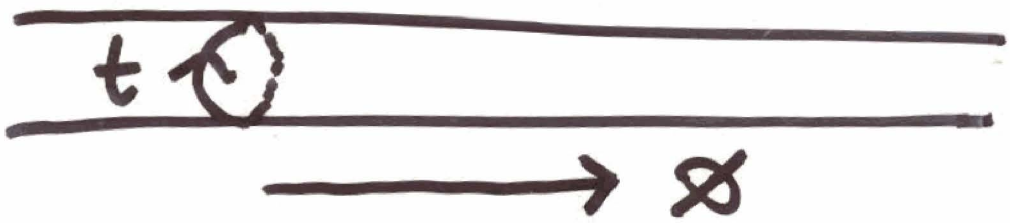
$$\mathbb{R}^{3,1} \times S^1 \times \tilde{S}^1 \times M_4$$

Heterotic String on $\mathbb{R}^{3,1}\times\tilde{S}^1\times S^1\times\mathcal{M}_4$

Add magnetic charge:

$\tilde{W}$ NS5-branes on $S^1\times\mathcal{M}_4$

CHS



w/ Linear Dilaton

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

$$\mathbb{R}_t\times\mathbb{R}_\phi\times\underbrace{SU(2)}\times S^1\times\mathcal{M}_4$$

$\tilde{N}$ KK-monopoles on $S^1\times\mathcal{M}_4$

BPS

GPS
KLL

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

Add Energy M

$\ell_s \simeq 1$

$g_s^2 \ll 1$

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

$$\text{MS} \quad \mathbb{R}_\phi \times \mathbb{R}_t \longrightarrow \frac{SL(2)_k}{U(1)}$$

2-d BH

Altogether:

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

$$\frac{SL(2)_k}{U(1)} \times S^1 \times \frac{SU(2)_k}{\mathbb{Z}(\tilde{N})_L} \times \mathcal{M}_4$$

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

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

HHS
GKRS

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

2-d BH w/ 2 charges

$$J_L = J \sin\alpha_L + J^3 \cos\alpha_L$$

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

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

Entropy:

GKRS

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

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

$M^2 - q^2 \gg 1$

Exact in $\alpha' = \ell_s^2$

Leading order in $g^2_{hor.} \simeq \frac{1}{S}$ and g_s^2

Special cases:

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

① Extremal

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

$M^2 = q_L^2 - 1$, -11- q_R Non-BPS

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

GKRS × KLL

$$\boxed{AdS_2} \times S^1 \times S^2 \times \tilde{S}^1$$

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

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

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

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

$$F_{\theta\phi}^{(\tilde{G},\tilde{B})} \simeq (\tilde{N}, \tilde{W}) \sin\theta$$

$AdS_2 \times S^2$

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

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

- Relation w/ other works:

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

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

⋮

Extremal, non-BPS Kraus-Larsen Sahoo-Sen

② very extremal

$$M^2 = q_R^2 = q_L^2 - 1 \quad \text{(say, } n=0\text{)}$$

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

GKS
KLL

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

③ Small BH (perturbative F1)

$\tilde{N} = 0$

$$\frac{SL(2)_2 \times U(1)}{U(1)} \times \{\bar{\Psi}_1, \bar{\Psi}_2, \bar{\Psi}_3\} \times \mathcal{M}_4$$

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

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

for **any** $(M; q_L, q_R)$

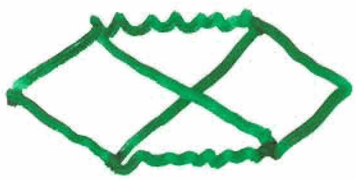
• Proposal (say, in type II):

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

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

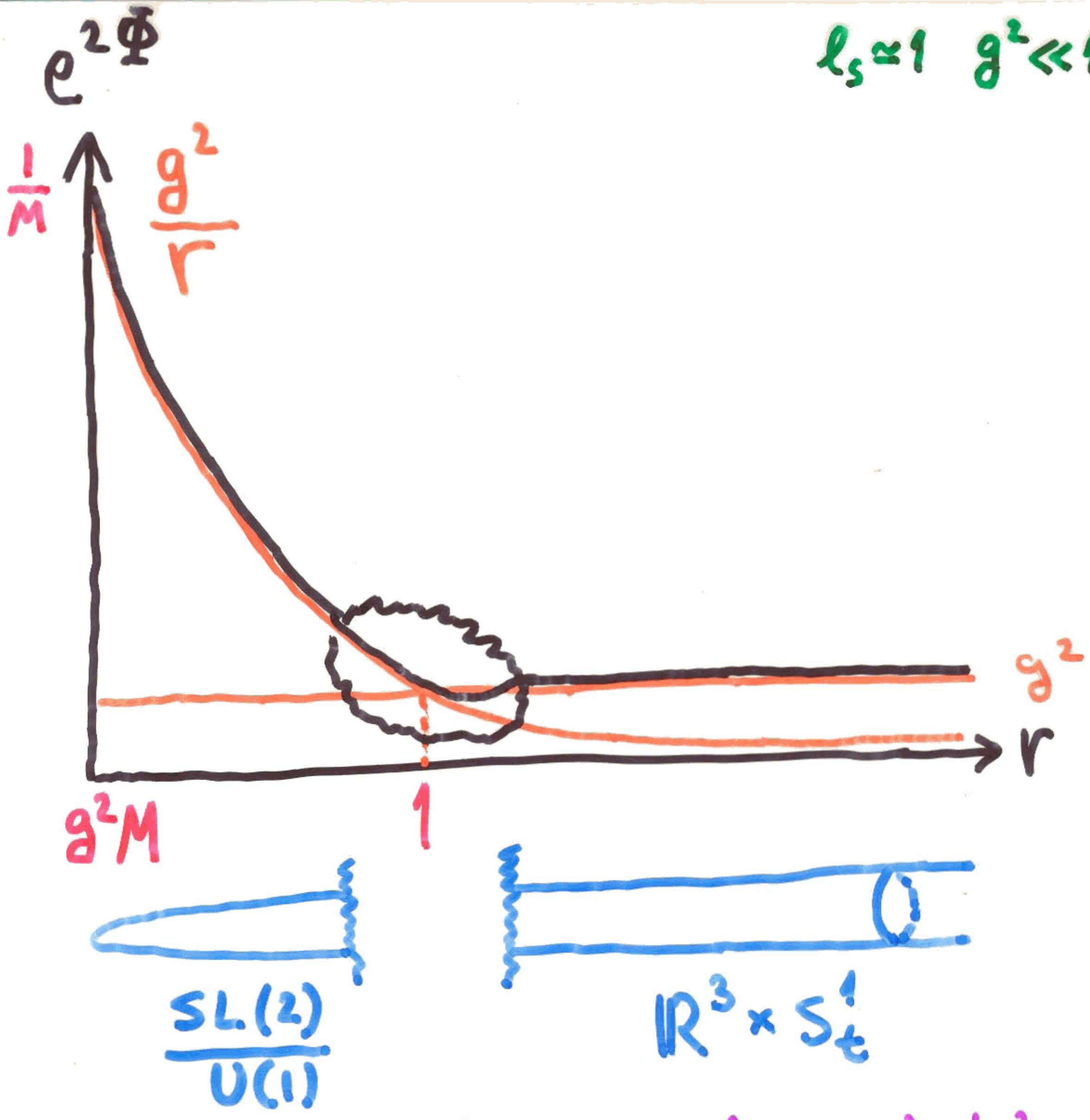
• $q_L = q_R = 0$:

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



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

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



$$ds^2 = -f dt^2 + \frac{d\rho^2}{f\rho^2}$$

$$f = 1 - \frac{2M}{\rho}$$

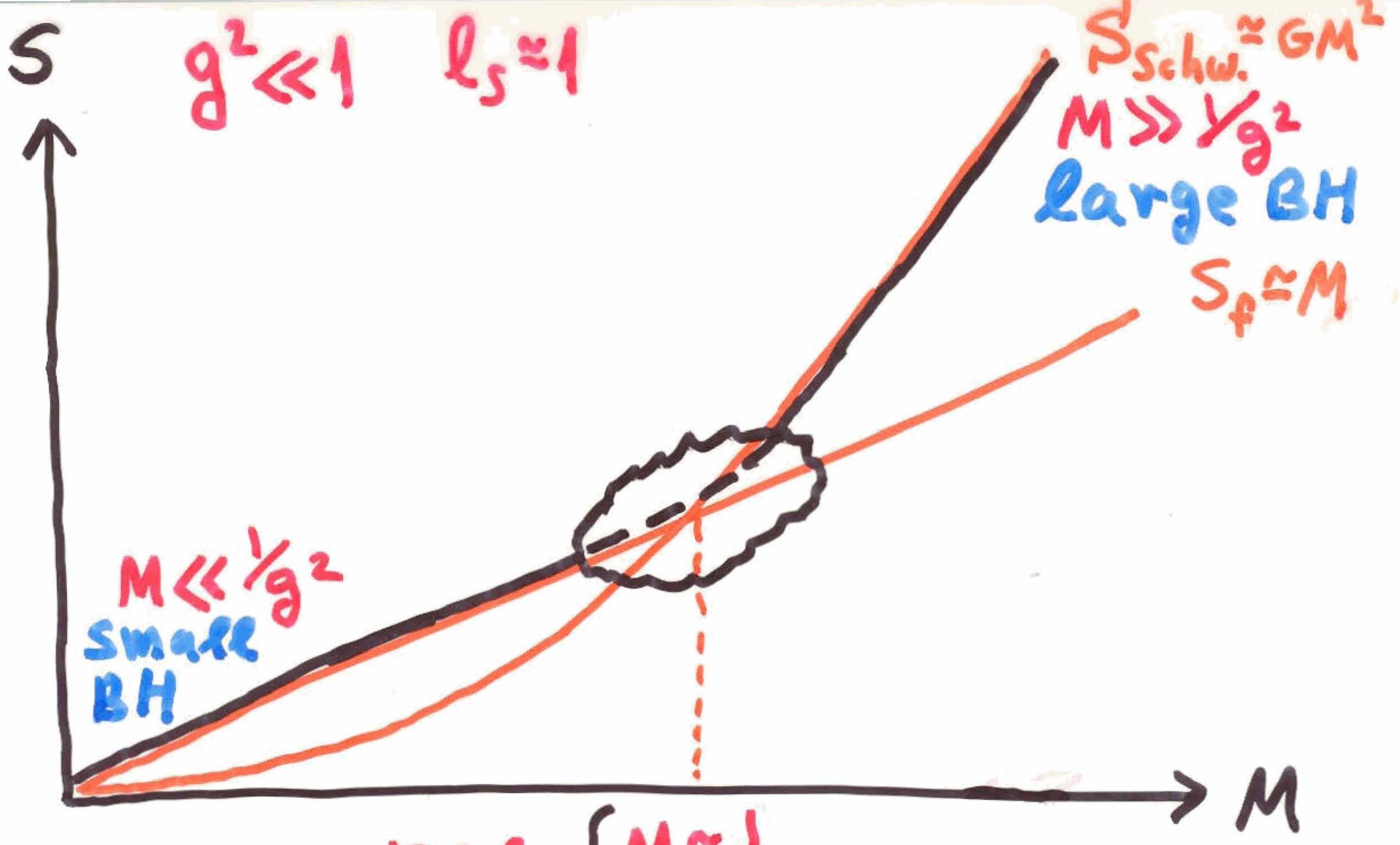
$$e^{-2\Phi} = \rho \simeq \frac{r}{g^2}$$

$$ds^2 = -f dt^2 + \frac{dr^2}{f} + r^2 d\Omega_2$$

$$f = 1 - \frac{2GM}{r}$$

$$G \simeq g^2$$

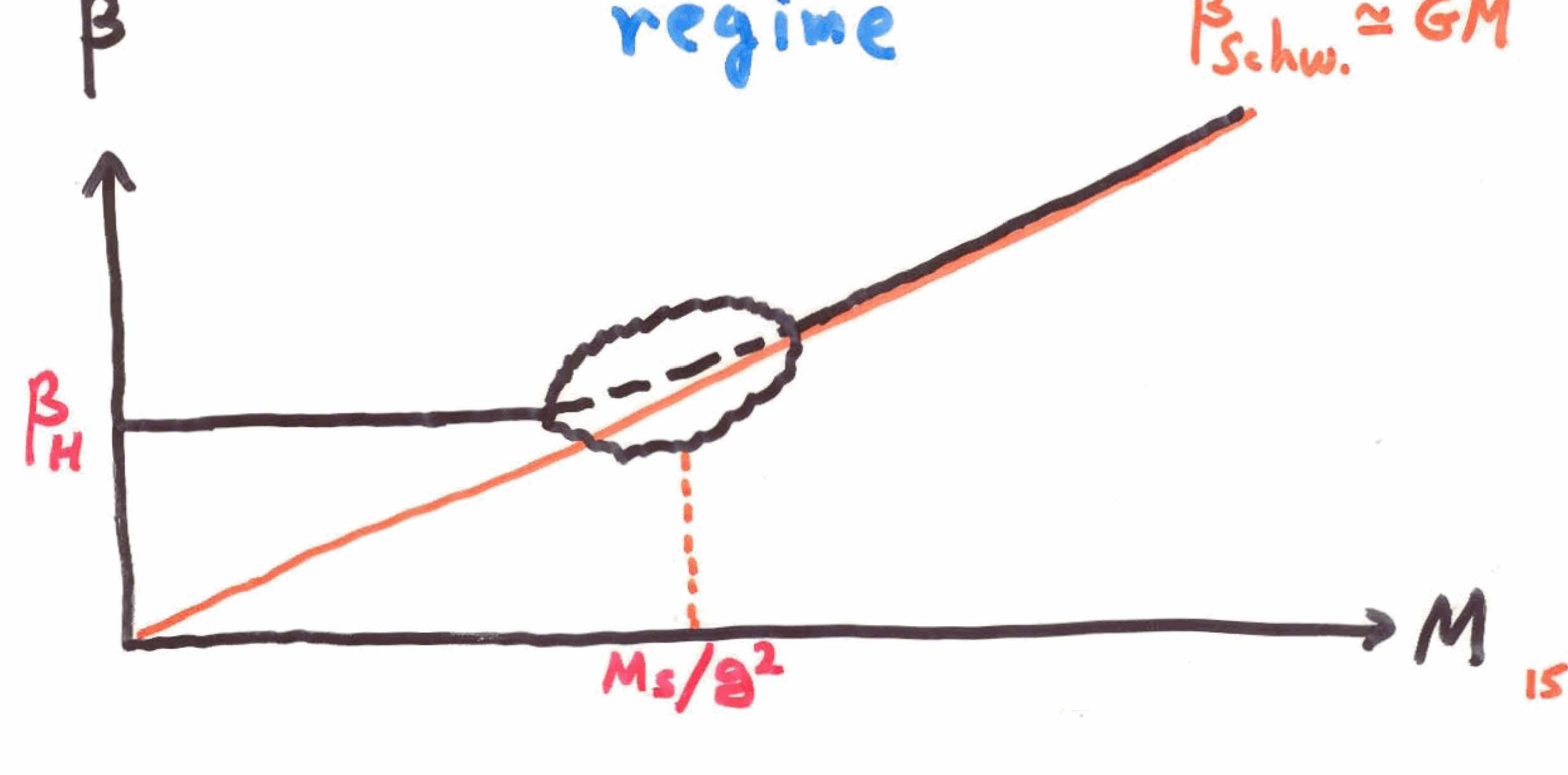
$$r_h \simeq g^2 M$$

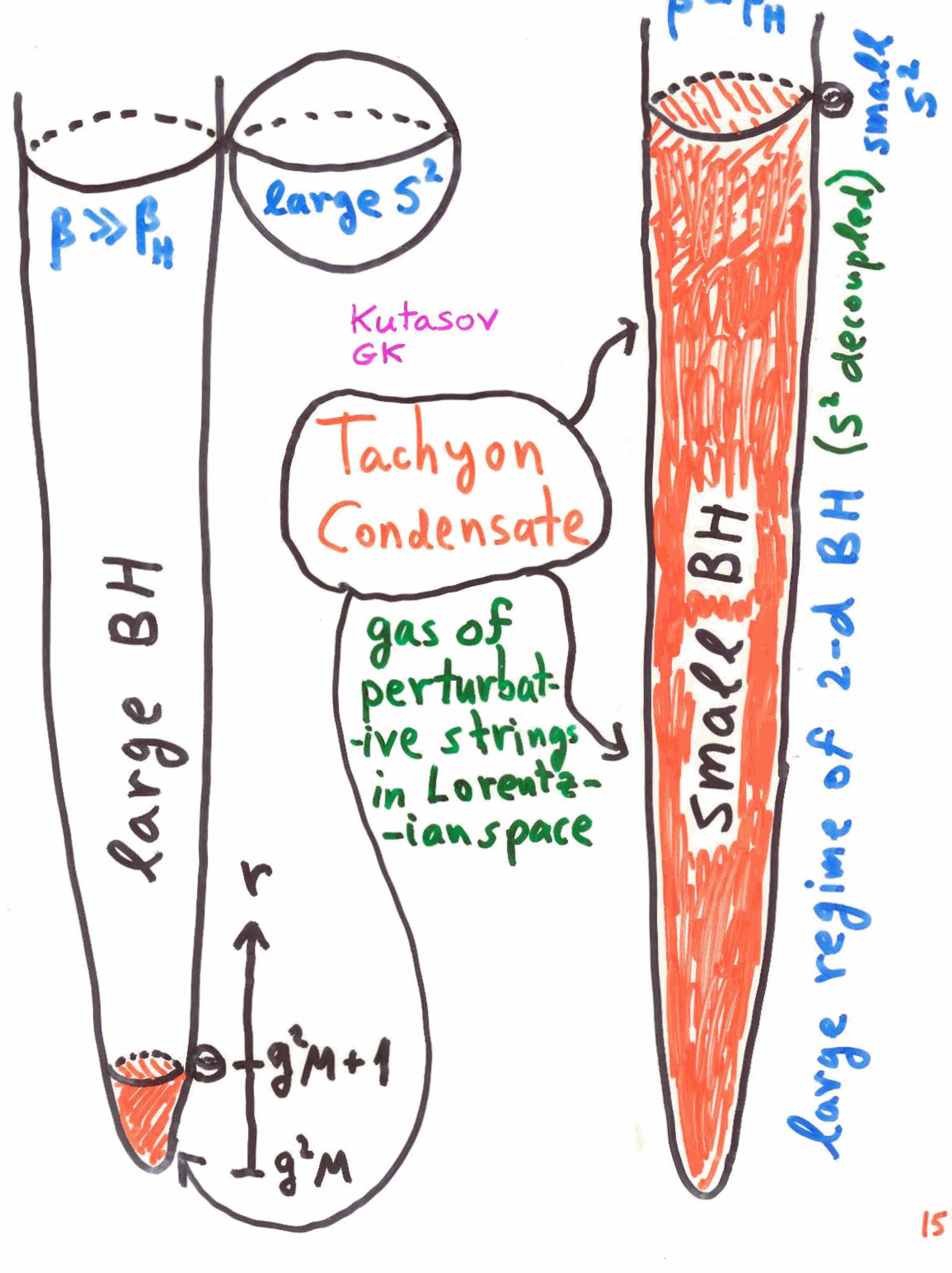


$r_h \simeq l_s \Rightarrow \begin{cases} M \simeq \frac{1}{g^2} \\ S_{Schw} \simeq S_f \end{cases}$

Veneziano
Susskind
Horowitz-Polchinski
:

correspondence regime

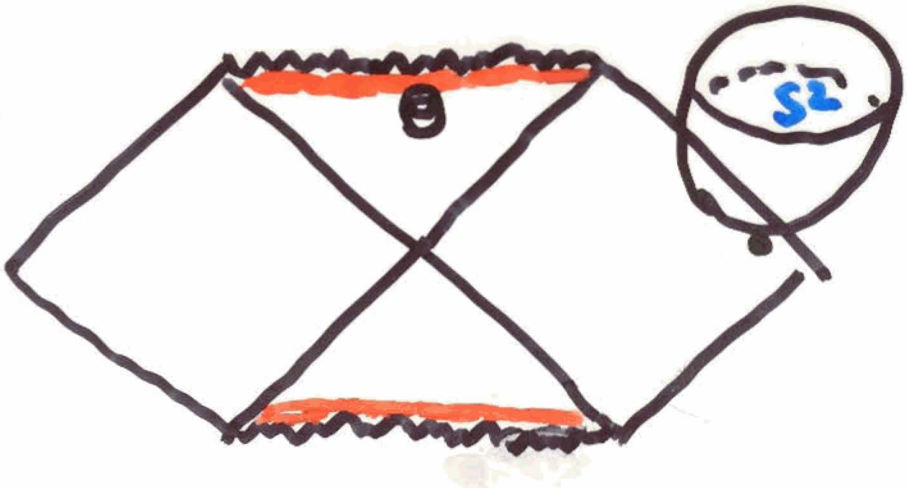




$\beta \gg \beta_H$
large S^2
large BH
r
g^2M+1
g^2M
Kutasov
GK
Tachyon
Condensate
gas of
perturbat-
-ive strings
in Lorentz-
-ianspace
$\beta \approx \beta_H$
small S^2
small BH
large regime of 2-d BH (S^2 decoupled)

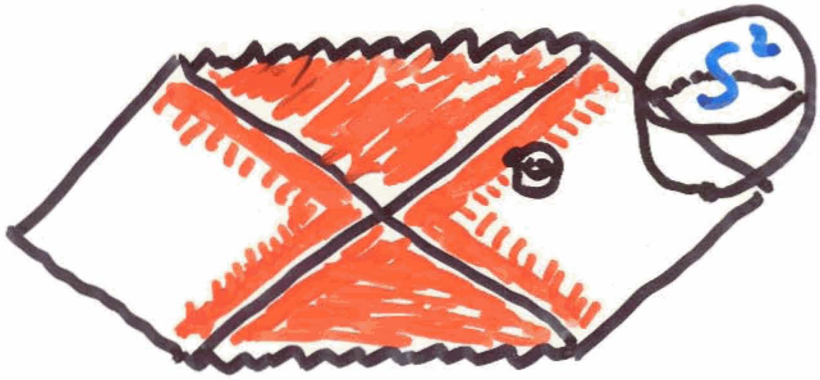
15'

more speculative



large BH

2-d BH regime



small BH

15''

- Resolution of the black hole singularity:

  4-d $\longrightarrow$ 2-d

- Evaporation
- Scattering; Absorption
- Information